Initial Risk Assessment of Alien Species in Nordic Coastal Waters

Stowaways of the sea!

Some 3000 to 4000 marine species of plants and animals travel at any given time from one of the world's seas to another, most of them in the ballast water tanks of ships. Alien water-living organisms are known to cause considerable ecological and economic damages in the new areas and ecosystems they are introduced to. There are several What's and Why's to be answered: Why did they arrive now and not tens of years ago? Are they here to stay? Why are some port areas more open to alien species than others? Why do some of them spread dramatically and become pests? Some of them have appeared to be beneficial - are they a potential resource or a threat?

This report provides a first attempt to assess the environmental risks related to alien invasions into the Nordic seas. These invasions are a present and future concern for shipping industries and maritime authorities and a challenge for marine biologists.

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Nordic Council of Ministers

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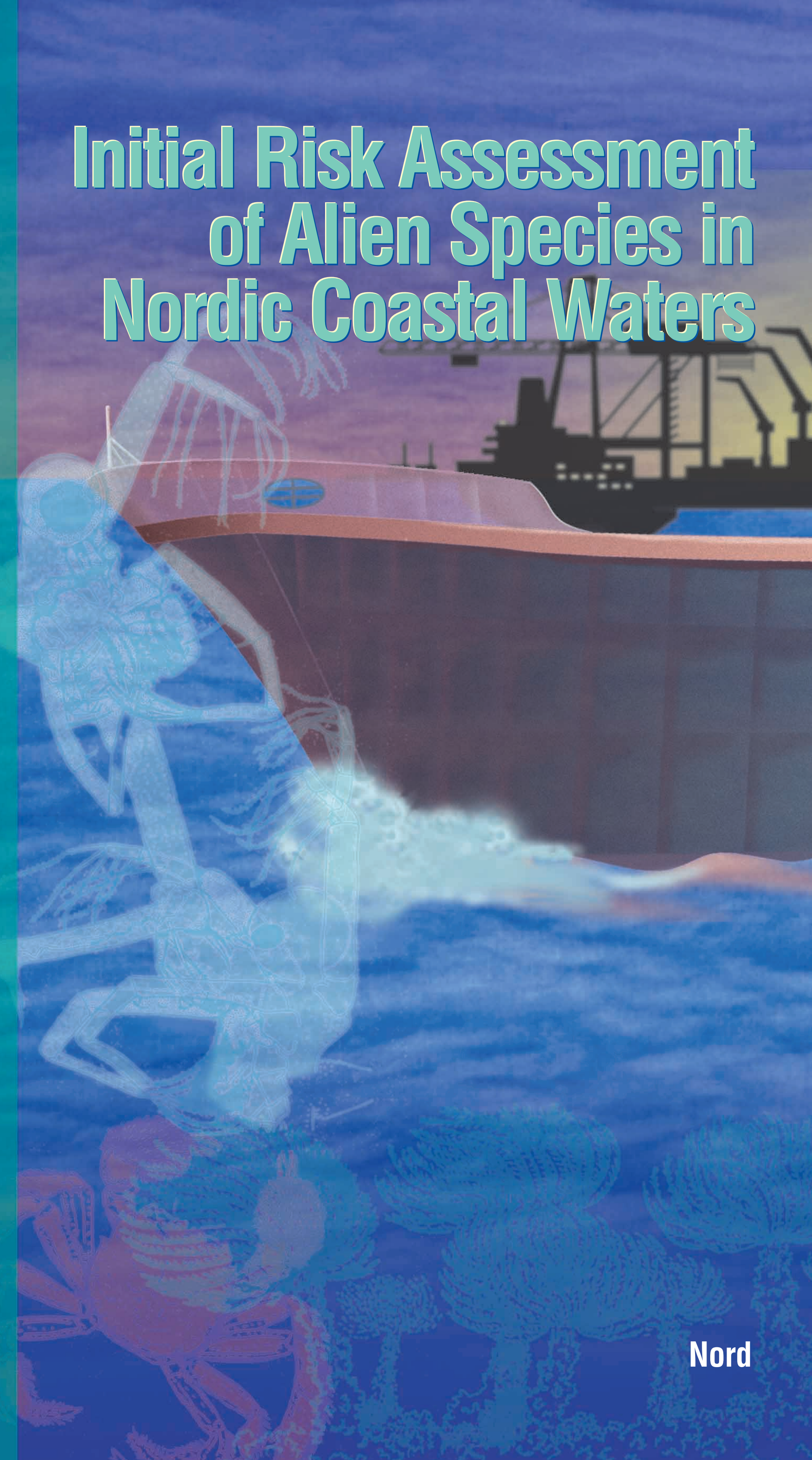

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Nordic Environmental Co-operation
Environmental co-operation is aimed at contributing to the improvement of the environment and forestall problems in the Nordic countries as well as on the international scene. The co-operation is conducted by the Nordic Committee of Senior Officials for Environmental Affairs. The co-operation endeavours to advance joint aims for Action Plans and joint projects, exchange of information and assistance, e.g. to Eastern Europe, through the Nordic Environmental Finance Corporation (NEFCO).

The Nordic Council of Ministers
was established in 1971. It submits proposals on co-operation between the governments of the five Nordic countries to the Nordic Council, implements the Council's recommendations and reports on results, while directing the work carried out in the targeted areas. The Prime Ministers of the five Nordic countries assume overall responsibility for the co-operation measures, which are co-ordinated by the ministers for co-operation and the Nordic Co-operation committee. The composition of the Council of Ministers varies, depending on the nature of the issue to be treated.

The Nordic Council
was formed in 1952 to promote co-operation between the parliaments and governments of Denmark, Iceland, Norway and Sweden. Finland joined in 1955. At the sessions held by the Council, representatives from the Faroe Islands and Greenland form part of the Danish delegation, while Åland is represented on the Finnish delegation. The Council consists of 87 elected members - all of whom are members of parliament. The Nordic Council takes initiatives, acts in a consultative capacity and monitors co-operation measures. The Council operates via its institutions: the Plenary Assembly, the Presidium and standing committees.

Contents

Foreword

The introduction of species to habitats outside their native ranges is increasing around the globe and represents a growing problem due to the unexpected and unwanted impacts these species might cause. Since the mid of this century the number of introduced species has increased heavily.

Knowing that each single introduced species has the potential to cause severe damage or harm to the environment and/or economy, makes risk assessment of present and future introductions one of the most crucial issues.

Water-living nonindigenous species (often called aliens, exotics, nonnative or introduced organisms) are predominantly transported intentionally for aquaculture purposes or unintentionally with interregional and international shipping. Vessels provide habitats for a large variety of organisms due to their transport of ballast water, sediments in ballast tanks and hull fouling.

The introduction of non-indigenous species is a global issue. According to the well known advice "think globally - act locally" this report is the first step towards the evaluation of the risk of future species introductions focusing specifically on the Nordic coastal waters.

This is the first report from a project called "Risk Assessment for Marine Alien Species in the Nordic Area". The project was funded in 1997-1998 by the Nordic Council of Ministers. The report was written for the reader of the scientific and non-scientific community.

The responsibility for the statements in this report is entirely ours, and could not be interpreted as the official policy declaration of the Nordic Council of Ministers.

We gratefully acknowledge the initiatives taken by the Nordic Council of Ministers enabling the preparation of this report.

January 1999

The authors

Summary

Alien (nonindigenous, exotic) species are currently present in the coastal waters of all of the Nordic countries. The movement of ballast water by ships is the largest single source of aliens' transfer throughout the world today.

Once a species has become established, control activities are likely to be difficult and costly. Therefore, the goal must be to prevent introductions of non-native species into the Nordic area and their secondary dispersal within the area. Marine biologists have to detect new introductions in a timely manner, assess whether they should be regarded as potentially harmful, and monitor the distribution and ecological impacts of invasive species of foreign origin.

Through literature review a semi-quantitative model (low - medium – high risk) has been developed and applied to five representative ports in Nordic waters, including the Baltic Sea, the Kattegatt, the Skagerrak and the North Sea. Desk studies elucidate the main transport routes for ballast water imported to and from these ports in the Bergen area (Norway), Stenungsund area (Sweden), Klaipeda (Lithuania), Turku/Åbo (Finland), and St. Petersburg (Russia). Individual physical, chemical and biological profiles of the harbours are provided. Further inventories of volumes and patterns of ballast water are needed for assessing the scope and significance from a regional perspective, and to identify risk areas (donor as well as recipient area) for introductions.

Information is presented on the current key species and the most important target species likely to invade Nordic coastal waters in the future. Examples from Nordic and other temperate environments are given on ecosystems at risk and potential and actual effects of nonindigenous species.

Documentation of economic impacts of introduced species is still unsufficient for analyses of costs of effects on maritime industries, underwater constructions or costs caused by fouling of alien species in industrial (e.g. cooling water of power stations) and shipping. Any commercial benefits of nonnative species should also be included in the analyses.

An international outlook is based on information available from e.g., North Sea, Black Sea, the USA (Great Lakes, Chesapeake Bay, San Francisco Bay) Australia and New Zealand.

Sammandrag

Idag finns främmande (icke-ursprungliga, exotiska) arter i alla Nordens kustvatten. Fartygens barlastvatten är den största enskida orsaken till främmande arters förflyttning runt jorden.

Då en art redan fått fotfäste i ett område är det oftast svårt och kostsamt att kontrollera deras forsatta spridning. Av denna orsak bör målsättningen vara förebyggandet av icke-ursprungliga arters etablering och sekundära spridning i Norden. Marinbiologer bör sträva till att upptäcka introducerade arter i tid, uppskatta deras eventuella skadlighet samt att hålla spridning och ekologisk påverkan av främmande invasiva arter under uppsikt.

En litteraturöversikt har gett grunden till en semikvantitativ riskmodell (låg - medel - hög risk) som använts för fem representativa hamnar i Norden. Dessa hamnar omfattar Östersjön, Kattegatt, Skagerrak samt Nordsjön. Det har varit möjligt att beskriva huvudtransportrutterna för barlastvatten från och till dessa hamnar i Bergenområdet (Norge), Stenungsundområdet (Sverige), Klaipeda (Litauen), Åbo (Finland) samt St. Petersburg (Ryssland). Hamnarna beskrivs fysikaliskt, kemiskt och biologiskt i individuella hamnprofiler. Fortsatta undersökningar av barlastvattenvolymer och transportmönster behövs för att uppskatta den vidd och betydelse det har regionalt samt för att identifiera riskområden (donerande samt mottagande områden) som kan vara känsliga för introduktioner.

De nuvarande nyckelarterna och de viktigaste målorganismerna som kan förväntas invadera Nordens kustvatten i framtiden finns presenterade i boken. Exempel från Norden och andra tempererade områden ges på ekosystem i farozonen samt möjliga och verkliga effekter av främmande arters invasion.

Introducerade arters ekonomiska effekter är idag inte tillräckligt dokumenterade för att möjliggöra kostnadsanalyser av effekter på industrin (t. ex. kraftverkens kylvatten) och sjöfarten. Eventuella kommersiella fördelar bör även beaktas i analysen.

En internationell översikt baserar sig på information från t. ex Nordsjön, Svarta havet, USA (Great Lakes, Chesapeakebukten, San Francisco bukten), Australien samt Nya Zeeland.

1. Introduction

All ecosystems, terrestrial and aquatic, all over the world are invasible by nonindigenous species (NIS). It is assumed that the main vector concerning transportation of alien marine organisms is, beside the introduction of species for aquaculture purposes, the unintentional transport with ships.

In 1903 the first record of a step-mediated species introduction to European waters occurred in the North Sea. The planktonic algae *Odontella* (*Biddulphia*) *sinensis* (see below) bloomed and were therefore recorded. It was assumed that ships introduced the algae (Ostenfeld 1908). The first scientific shipping studies including sampling of ships' ballast water appeared 70 years later by Medcof (1975) followed by those of Carlton (1985, 1987), Hallegraeff & Bolch (1991) and Subba Rao *et al.* (1994). Rosenthal (1980) summarised the knowledge of and the risks associated with the intentional introduction of nonindigenous species for fisheries and aquaculture purposes. In addition, ballast water was mentioned as a vector for unintentional species introductions. The study concluded that modern aquaculture development in the coastal zone was at high risk of disease transfer via ballast water, in cases where aquaculture facilities and areas of fishing were located near shipping routes.

After having been made aware of the problems, the ICES[1] established a working group (WGITMO[2]) in the end of the 1970s in order to evaluate quarantine measures dealing with imports of species for aquaculture and accordingly developed an ICES "Code of Practice" (see below) (Carlton 1991, 1992, Sindermann 1992, ICES 1995 a, b). In 1995 the ICES WGITMO further emphasised the need to follow the IMO[3] Assembly Resolution A.868 (20): "Guidelines for the Control and Management of Ship's Ballast Water to Minimise the Transfer of Harmful Aquatic Organisms and Pathogens" (see below). In addition to the WGITMO, ICES, IOC[4] and IMO there was a joint Study Group established in 1997 (SGBWS[5]) focussing on the unintentional introductions by ships.

Other regional bodies particularly relevant in this field are a working group of the BMB[6] on Nonindigenous Estuarine and Marine Organisms, an *ad hoc* group established in 1994 with a term of reference covering 4-5 years. Objectives of the Working Group are:

- to collect and summarise information on introduced species in the Baltic Sea in order to make a co-operative report covering their role in the ecosystem they invaded

[1] ICES = International Council for the Exploration of the Sea

[2] WGITMO = Working Group on Introductions and Transfers of Marine Organisms

[3] IMO = International Maritime Organization

[4] IOC = International Oceanographic Commission

[5] SGBWS = Study Group on Ballast Water and Sediments

[6] BMB = Baltic Marine Biologists

- to promote a closer co-operation between biologists dealing with introduced species within the Baltic Sea and between the Baltic Sea and other marine areas, and
- to elaborate recommendations for HELCOM[7].

A statement to HELCOM made by the Working Group at its first meeting in Klaipeda in 1995 was appreciated by the HELCOM EC[8]. In the Baltic Sea context the issue has been touched several times by HELCOM EC and MC[9].

NIS are not only introduced with ballast water and associated sediments, but also as fouling organisms on the ship's hull. However, efficient biocidal antifouling paints currently used (see further below) considerably reduce the number of fouling organisms on ship's hulls. Accordingly, the major problem in transmission of harmful aquatic organisms, therefore, resides with the continued transfer of ballast water of ships. It has been estimated that the major cargo vessels of the world transfer 8-10 billion tons of ballast water per year indicating a global concern for this problem. It has been demonstrated that in average 3,000 (Carlton & Geller 1993) to 4,000 species (Gollasch 1996) are transported by ships daily.

The influences of mankind on the sea result in pollution, loss of biodiversity due to overexploitation of living resources, habitat deterioration and the introduction of NIS. Introductions of NIS in the aquatic environment represent a growing concern all over the world. A number of alien species have become established in the Nordic seas. During the last 150 years about 90 species have been introduced by human activities into the Baltic Sea. Most of these species have been introduced unintentionally by ballast water or as fouling on ship hulls. Other species were intentionally introduced for aquaculture or experimental purposes. The comparably species-poor communities of the Baltic Sea are probably more sensitive to the successful introductions of NIS than other areas characterised by a higher biodiversity. Future species introductions may increase due to the increasing shipping traffic, knowing that ships are the main vector of introduction of NIS (Leppäkoski 1984, 1994, Jansson 1994, Gollasch 1995, Gollasch & Mecke 1996, HELCOM 1996). The occurrence of introduced species has increased the threats to human health and the marine environment (Kononen *et al.* 1996).

1.1. The need for ballasting and what is ballast water?

Already Viking sailing vessels used ballast to stabilise and trim the vessels that crossed the oceans. In these historical times solid ballast (sand, gravel or stones) was used (Lindroth 1957). Since the 1870s water ballast has been used when ships have not been fully loaded, in order to submerge the propeller and rudder in the water, to operate effectively and to control the trim and increase the stability. Ballast water is carried in segregated ballast water tanks or in emptied cargo holds of bulk carriers. Ballast water is marine or fresh water taken on board in ports, waterways or the open ocean (Carlton 1985, 1987, 1994). With the intake of ballast water, organisms in the water are pumped on board into the ballast tanks. Sediments suspended in the water may settle to the

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[7] HELCOM = HELsinki COMmission

[8] HELCOM EC = HELCOM Environment Committee

[9] HELCOM MC = HELCOM Maritime Committee

bottom of the ballast tanks or cargo holds. Some decades ago ballast water was often contaminated with oil, reducing the survival rate of species in transit.

Ballast water is carried in a wide variety of shape of ballast tanks and cargo holds. Almost all vessels always carry ballast water when they are not carrying cargo. Loaded ships contain ballast water as well, even if they are loaded to the maximum (Carlton 1994) and some container vessels even fill up with ballast water when loading. Depending on the construction of the tanks and pipework, several tons of residual water can remain in ballast tanks emptied to the maximum. Depending on the trade statistics of a country, it is classified mainly as importing cargo (no ballast water necessary to be transported in fully loaded vessels) or exporting goods. Countries characterised by a surplus in exporting cargo will usually record empty vessels calling for their ports, in order to load a maximum of cargo for their voyage. These vessels (especially bulk carriers and oil tankers) will carry large amounts of ballast water that has to be discharged in the ports and waterways.

1.2. The need for ballast water management

The great number of unwanted nonnative species introduced all over the world called for a need to develop treatment options in order to minimise the amount of further species introductions. The eradication of an introduced species that establish in a new marine environment will either be very expensive or even impossible. Therefore, high priority should be given to efforts that prevent or minimise introductions.

Ballast water has in most cases been taken on board in areas far away. During the intake of the ballast water, organisms, sediment and contaminants, may have followed, especially if the area of intake is shallow. If the ballast water is released, some sediment and organisms that survived the voyage will also be discharged.

It is impossible to predict the effects which these introductions will cause to the ecology (e.g. competition to and replacement of native species) and economy (e.g. harmful organisms threatening aquaculture sites, damaging port installations, causing diseases, reducing the aquaculture production etc.; Box 3-5 below) in the recipient area.

The impact of any introduced species is unpredictable because of the extremely high number of parameters involved (Courteney & Taylor 1986). A species showing no negative impact in its area of origin (the donor area), may cause serious damages to economy and ecology to a new locality (the recipient area) where it has been intentionally or unintentionally introduced. Negative effects could e.g. be the limitation of food sources for native species during mass occurrences of the introduced species, unwanted introduction of parasites and disease agents, or extinction of native species (worst case if these are commercially harvested) (Rosenthal 1980, Williams & Sindermann 1991, Kern 1994, Grosholz & Ruiz 1995, Holmes & Minchin 1995).

2. Main habitat characteristics of the Nordic sea areas

The Nordic waters with their coastlines along the Baltic and North Sea as well as the North Atlantic, offer gradients from fully marine to greatly diluted close to freshwater conditions, and therefore, a general picture cannot be drawn. The Baltic Sea may be characterised by a wider variety of habitats, mainly based upon a large variety of hydrographical and biological gradients over its entire water basin, than the North Sea with its typical marine conditions. The interaction between the North and Baltic Sea results in changing salinity conditions in certain areas (caused by changing influxes from the North Sea and freshwater river systems). The habitat surfaces in the Nordic region range from soft to hard bottom areas and provide suitable environments to a wide range of species (Tardent 1979, Leppäkoski & Bonsdorff 1989).

The North Sea is a shelf sea with a surface of 575,000 km^2 and an average depth of 94 m. The Baltic Sea is an enclosed sea (mean depth 55 m) and represents the worlds largest brackish water sea area with a total surface of 382,000 km^2. The Skagerrak´s coastal areas form the border between the oceanic North Sea and the freshwater influence of the Baltic Sea. The Baltic Sea is divided into seven different areas, known as the Kattegat, the Belt Sea, the Sound, the Baltic proper, the Gulf of Riga, the Gulf of Bothnia, and the Gulf of Finland (Tardent 1979, Wastenson *et al.* 1992, Bäck *et al.* 1996).

In this report we cover the whole gradient from the innermost Baltic Sea (St. Petersburg) to the Atlantic coast of Norway (Bergen), but for several reasons we focus mainly on the Baltic Sea, one of the most thoroughly studied seas in the world.

2.1. Climate and temperature

As the Baltic Sea is located in the west wind zone, winds from west and south west dominate the temperate weather. The cold-temperate climate is to a large extent coupled to the latitude of main cyclone tracks (HELCOM 1996).

The surface water temperature in summer varies between 14-16 °C within the entire Baltic Sea. In autumn the temperature differ with 8 °C. The temperature gradient in winter and spring is 6 °C from ice covered parts in the Bothnian Bay and Gulf of Finland to 6 °C surface water in western areas. Usually the ice cover in the northern Bothnian Bay lasts for 170-190 days. In the Archipelago Sea ice cover can occur 70 days and in the southern part of the Baltic proper less than 20 days (Kullenberg 1981, National Board of Survey & Geographical Society of Finland 1993). Furthermore, ice may also occur in inner parts of bays and fjords on the Swedish west coast (see 23).

2.2. Salinity

The salinity gradient in the Baltic Sea leads to naturally different species communities and offers therefore a wide variety of habitats.

The water exchange with the North Sea is characterised by two currents: the eastward deeper current carrying saline North Sea water into the Baltic Sea and up to the Finnish coasts and the westwards directed surface water current carrying lower saline waters from the Baltic Sea to the North Sea (Wastenson *et al.* 1992, Bäck *et al.* 1996). As a result, the salinity declines from west to east and from south to north. The North Sea is characterised by salinities higher than 30 PSU. Between the Skagerrak and the Kattegat the surface water salinity decreases to 25 PSU. A great decrease occurs in the area between the southernmost part of Sweden and the German island Rügen (8-9 PSU). The entire Baltic proper (up to the south coast of Finland) is characterised by salinities of 6-8 PSU.

The lowest salinities, up to freshwater conditions, are found in the northernmost part of the Bothnian Bay and the easternmost part of the Gulf of Finland (Aario *et al.* 1960, Wastenson *et al.* 1992; see 26).

2.3. Topography and sediment surface

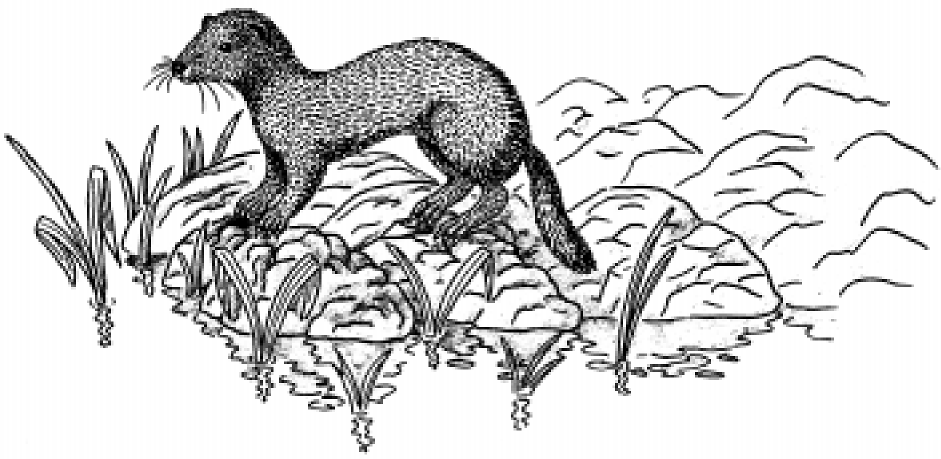
The coastal areas of the Baltic Sea are divided into archipelagos, fjords, open low coast, klint coast, lagoon and bodden type areas (Winterhalter *et al.* 1981, Håkansson 1990). In the Baltic proper the average depth is 60 m. Shallow areas (less than 10 m depth) represent about 17 % of the entire area.

Sedimentary maps show that soft bottom areas are the prevailing seabed structures in the open sea. Apart from glacial clay, postglacial clay and silt and hard bottom areas occur. In addition to natural hardbottom areas (e.g. gravel, stones and concrete rocks) man-made installation at ports, marinas and coastal protection installations offer a variety of additional hard bottom habitats.

In coastal areas hard bottom structures prevail. In Finland 42 % of the coast is characterised as bedrock, approx. 10 % as mud and approx. 5 % as sand. About 1.3 % of the Finnish coastline is human mediated constructions, such as ports, banks and dams (Wastenson *et al.* 1992, Bäck *et al.* 1996, see 25).

2.4. Biotic features

In the Baltic Sea the number of species is much lower compared to marine areas, e.g. the Atlantic Ocean. Only less than 3 % of the marine macroinvertebrates occurring in the waters of the Skagerrak are able to survive the water conditions in the Bothnian Sea. In addition, winter conditions result in a shortened growing season and ice abrasion negatively effects the survival of species. On the other hand the number of submersed higher plants and charophytes on shallow sediments are much higher than along the true Atlantic coasts due to the number of freshwater species inhabiting the area. The short geomorphological history of the Baltic Sea and the changes of the salinity from freshwater to marine periods, has to be taken into account. As a result, the number of endemic species in the Baltic Sea is very low (Wallentinus 1991). However, the brackish nature of the Baltic Sea does not protect it from introductions of NIS. Nonnative species recorded from the Baltic Sea were documented by Leppäkoski (1984, 1994), Jansson (1994), Gollasch (1995) and Gollasch & Mecke (1996) and summarise to nearly 100 species. It is assumed that about 70 species have been established as self reproducing populations until today.



Mustela vison, the North American mink

3. Nonindigenous species in coastal and adjacent waters

3.1. Nordic countries

In the Nordic countries Sweden and Finland have compiled lists of alien species in their waters. The Swedish desk study revealed that about 70 NIS have been found along the Swedish coasts (Jansson 1994). Finnish studies collected references of about 45 species (Leppäkoski 1984, 1994).

An uncompleted literature research during this study revealed nearly 25 records of NIS in Danish waters (e.g. Knudsen 1989). In the west Norwegian Hordaland county area, 79 of the approx. 4,000 macrozoobenthic species occurring, are either nonnative or of unknown origin (cryptogenic species). It is not clear whether these species were introduced or if they reached the area by natural dispersal or if they are native to the area (Brattegard & Holthe 1997, see 22). Until today no study on introduced NIS has been undertaken in Iceland, but two introduced seaweeds (*Codium fragile* and *Bonnemaisonia hamifera*) have been recorded (Munro *et al*. in press, J. Svavarsson, pers. comm.). In spite of the lack of data it is assumed that most probably NIS do occur in Icelandic waters. The reason for not being aware of the problem might be the unique situation that present NIS do not cause harmful effects to the environment and do not impact local industries, and have therefore been overlooked for a long period of time.

3.2. Europe (excl. the Nordic countries)

Desk studies of selected European countries revealed that there are 53 NIS of macrofauna and flora in British waters (England, Scotland and Wales), 24 exotic organisms in Cork harbour (Ireland), and more than 100 in German waters (North Sea and the Baltic Sea). At least half of these species are believed to have been introduced by shipping. In Cork harbour (Ireland), 8 of the 24 species were introduced prior to 1972 and 4 of these are believed to have been introduced via ship hull fouling. Since 1972 antifouling paints of ships have generally contained tributyltin (TBT) and its use has considerably reduced the risk of introduction of fouling organisms. On the other hand the TBT is highly toxic and the leaching of the poisonous component of the antifouling paint pollutes the environment. In some areas (ports, shipyards and high frequent shipping routes) the accumulation of the TBT prevents the reproduction of several gastropod species. Therefore, in the beginning of the 1990s the TBT was banned to be used for boats smaller than 25 m. Other studies have shown that micro- and macroalgae are also affected. Due to the lack of an alternative effective and environmentally sound antifouling system, the use of the TBT in commercial vessels continues.

The increase of annual ballast water discharges in Cork harbour has increased from less than 20,000 tons in 1955 to almost 200,000 tons since the 1970s. Some of the nonnative species are economically important and have been introduced intentionally for aquaculture purposes. Several species may also have been brought unintentionally by the import of living Japanese oysters. Along the Atlantic French coast there are more than 10 introduced seaweed species (Munro *et al.* in press). In addition, some other species, pests and parasites, which adversely affect native species by competing for food and space, and replacing native species, have been introduced unintentionally (Farnham 1980, Leppäkoski 1984, 1994, Knudsen 1989, Utting & Spencer 1992, Gollasch 1996, Gollasch & Mecke 1996, Eno 1996, Eno *et al* 1997, Minchin 1997).

3.3. Mediterranean Sea

Nearly half of the more than 145 species, known to have been introduced and established in the western Mediterranean Sea, are believed to be introduced by shipping (Ben-Tuvia 1953, Rubinoff 1968, Ben-Eliahu 1972, Walford & Wicklung 1973, Krapp & Sconfietti 1983, Zibrowius 1991, Boudouresque *et al.* 1992, Boudouresque 1994, Galil 1994). The number of NIS in the eastern Mediterranean Sea is assumed to be higher than 300. Most of these species actively migrated into the Mediterranean Sea via the Suez Canal. In total more than 450 NIS can be found in the Mediterranean Sea (Galil pers. comm.).

3.4. Black Sea

More than 35 NIS are known from the Black Sea biota including the comb jelly *Mnemiopsis leidyi* (see below) causing severe economical losses in earnings of the fishing industry (Zaitsev & Mamaev 1997, Leppäkoski & Olenin, submitted).

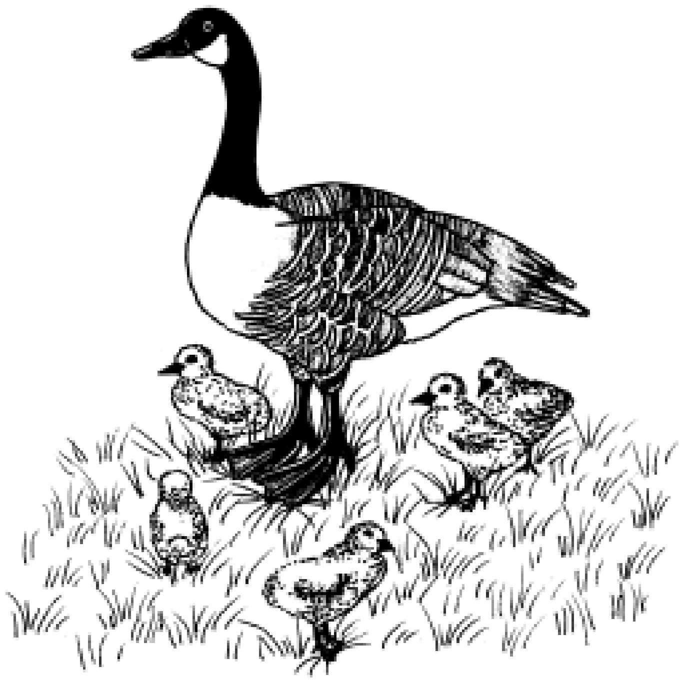
3.5. Australia

A total of 172 species are known to have been introduced and established into the Australian marine environment (Hoese 1973, Paxton & Hoese 1985, Hutchings *et al.* 1986, Hutchings 1992, Hallegraeff & Bolch 1991, 1992, Rigby *et al.* 1993), mostly through ballast water (Thresher pers. comm.). These include molluscs, crustaceans, polychaete worms, seaweeds and toxic phytoplankton species. Some phytoplankton species bloom and enter the food chain via shellfish feeding. Toxins of some phytoplankton species are known to cause Paralytic Shellfish Poisoning (PSP), which may paralyse or even kill humans who consume affected shellfish. Recent cases of damage resulted in the need to prohibit all harvesting of shellfish on the Huon River estuary in Tasmania, in Port Phillippe Bay, Victoria and in Port Jackson, New South Wales, following a bloom of introduced toxic phytoplankton algae (dinoflagellates) in 1993 (Jones 1991, AQIS 1993).

Viable toxic dinoflagellate cysts were found in up to 6 % of the vessels entering Australian ports (Hallegraeff and Bolch 1991, 1992). The list of organisms reported to have survived ship voyages in the ballast water of vessels may be extended after each world-wide sampling programme.

3.6. North America

The area, which is supposed to be the habitat with the highest numbers of NIS in the world, is the San Francisco Bay. In total 212 exotic species have been found until today (Carlton 1994, 1995, Cohen & Carlton 1995, 1998). In the Hudson estuary 120 NIS were found (Swanson 1995) and 139 nonindigenous aquatic species have been recorded from the Great Lakes (Mills *et al.* 1990, 1993). The total number of aquatic NIS in North America was estimated at approx. 400 (Carl & Guiget 1957, Bousfield & Carlton 1967, Carlton 1985, 1987, Mooney *et al.* 1986, Smith & Kerr 1992, Mills *et al.* 1993, Grosholz & Ruiz 1995, Smith 1995, Ruiz *et al.* 1997).



Branta canadensis, the Canada goose

4. Ships as vectors for the transport of organisms

As mentioned earlier several thousands of species are estimated to be transported around the world by ships every day. Until today, it has been estimated that about 500 species are known to have been transported via ballast water to habitats outside their native range and have become established. The difference between the number of transported (3,000-4,000) and established (500) species indicates that successful species introductions do not occur very often (Howarth 1981, Carlton 1985, 1987, Locke *et al.* 1991, Kelly 1992, Carlton & Geller 1993, Carlton *et al.* 1995, Müller 1995, Müller & Reynolds 1995, Gollasch 1996, Gollasch & Dammer 1996). However, it has to be taken into account that one single introduced species can cause severe harm to the economy and ecology of the habitat it was introduced to (see 6).

The high number of species carried in ballast water is an additional indicator for the need of ballast water management. Several studies show that more than 50,000 zooplankton specimens may be found per 1 m^3 of ballast water. Calculations revealed that a total of several 10.000s or even millions of organisms were transported in the ballast water of a single ship (Locke *et al.* 1991. 1993, Gollasch 1996, Kabler 1996). The German shipping study revealed that each vessel calling for a German port in average contained in its ballast water, tank sediment and on the ships hull in total more than 4 million specimens of macrofauna (Box 1; Gollasch 1996). The number of phytoplankton specimens was several times higher. Lenz *et al.* (in prep) listed up to 110 million phytoplankton specimens in 1 m^3 of ballast water and maximum of 150 cysts in 1 cm^3 of ballast tank sediment samples. A Canadian study showed that more than 10 million phytoplankton cells were collected in 1 m^3 (Subba Rao *et al.* 1994) and the content of viable cysts of the dinoflagellate *Alexandrium tamarense* in one ballast tank was estimated to be more than 300 million cysts.

As many as 22,500 phytoplankton cysts per cm^3 were found in tank sediments during Australian studies. Cysts of some phytoplankton species may remain viable under unfavourable conditions for up to 10 to 20 years (Hallegraeff & Bolch 1992).

The potential risk of negative impact of harmful phytoplankton species on marine aquaculture is obvious. Also other introduced species such as the European green crab (*Carcinus maenas*) and the North Pacific starfish (*Asterias amurensis*) have been shown to affect aquaculture. Since the early 1990s, the total annual world aquaculture production is estimated at about 26.4 million tons (FAO 1996). Therefore methods to treat or manage ballast water are necessary to prevent or at least minimise further unwanted species introductions:

(1) Shipping activities have increased over the past decades with corresponding increases of amounts of transported and released ballast water.

(2) The duration of ship voyages has decreased due to technical improvements resulting in faster ships, and consequently increased survival of organisms transported in ballast tanks. Increasing number of ship visits in ports cause multiple introductions, which increase the probability for the successful introduction/establishment of NIS.

(3) The amount of marine organisms transported in ballast water seems to be increasing. For example dinoflagellate blooms appear increasingly world-wide, probably due to changing environmental conditions (e.g. eutrophication) in both donor and recipient areas and climate changes. Therefore, the probability of these species uptake in ballast water is increased.

(4) Increasing world-wide aquaculture activities support the potential of the spread of diseases and parasites, which after their establishment in new areas, may be distributed further by ballast water uptake (Jones 1991).

(5) The increasing trade by ships enforced the construction of new ports, causing additional introductions of species and/or introductions from new regions.

(6) Improving water condition in ports lead to richer fauna and flora in the area of origin supporting the probability of uptake in ballast water (Carlton *et al.* 1995).

Therefore, the uncontrolled discharge of untreated ballast water is a major international problem. It is up to governments, environmental agencies as well as the shipping industries to make commitments to identify a solution to this very complex problem. The presence of human disease agents (e.g. Cholera bacteria) in ballast underlines the need for ballast water treatment. Ignoring the problems that may be caused by introduced species with ballast water, could be an analogue to an ecological roulette (Carlton & Geller 1993, Hedgpeth 1993).

4.1. Results of the first European shipping study on ballast water

Apart from other introducing vectors (intentional introduction of species from aquaculture and fisheries, including their epi- and endobionts; ornamental and scientific purposes; accidental releases in trading of seafood and ornamental species), shipping is believed to be the substantial vector for unintentional species introductions.

The first European shipping study (Gollasch 1996) was undertaken in 1992-1996, initiated and financed by the German Environmental Protection Agency (Umweltbundesamt, Berlin). The main objectives were to determine the variety of species introduced by ships and to evaluate the risks associated with species introduction by shipping. The total of 211 ships visited for sampling gave 334 samples (132 ballast water samples, 131 hull samples and 71 samples of the tank sediment). More than 60 % of the 404 determined species (ranging from microscopic algae to crustaceans, molluscs and fishes) were nonindigenous to German waters of the North Sea and the Baltic Sea (Box 1).

Box 1

Facts on ships as habitat

In average every single sampled ship* carried a certain amount of ballast water, hull fouling and tank sediment containing organisms, and has therefore the potential to introduce a nonindigenous species.

Habitat	Volumes	Million specimens
Ballast water**	310 tons	0.3
Ship hull fouling***	1000 m^2	2.0
Tank sediment***	100 tons	1.8
Total		**4.1**

*Data based on the results of first European shipping study (1992-1996). The number of ships visited was 211 for sampling in German ports (Gollasch 1996, Lenz *et al.* in prep.)

**of foreign origin only. Total amount of ballast on board in average about 3500 tons.

***estimated

4.1.1. Ballast water

All sampled vessels carried ballast water. During the shipping study unicellular algae were found in nearly all of the samples. In addition 75 % of the samples contained zooplankton. Species found ranged from microscopic larvae to 15 cm long fishes. In average about 1 animal was found per litre ballast water. Predominately crustaceans and larvae of bivalves and gastropods were found in the samples. A maximum of 12 faunal species was found in a single sample of ballast water, in average 4 animal species. When the estimated amount of ballast water discharged in German waterways and ports is taken into account, about 70 specimens of foreign origin are introduced with ballast water every second or several million specimens per day.

4.1.2. Ships hull

The water-covered surface of the ocean going vessels investigated varied from 3,500 to more than 15,000 m^2. Of the sampled ships 98 % were covered with macroscopic fouling organisms. The surface area covered with fouling organisms was 1,000 m^2 on the average ships, being fouled in average by 18 animals per 10 cm^2, resulting in a wet weight of 6.6 tons per ship. The maximum thickness of fouling was 30 cm. A maximum of 15 faunal species was determined in one sample of the ships' hull. The average number of species was 6.2. In the literature about 2,000 species are known to be transported on ship hulls. Apart from sessile fouling organisms (mussels, barnacles, cnidarians and macroalgae) mobile organisms such as crabs can be transported in empty shells of ongrowing mussels or barnacles. Seaweeds and higher plants may also be entangled among other organisms.

4.1.3. Sediment in ballast tanks

Sediment in the uptaken ballast water will settle in the ballast tanks. The amount of sediment can reach several hundred tons. The maximum thickness of sediment known to be transported in ballast tanks was more than 50 cm. Of the ships sampled, 70 % contained sediment. In nearly 75 % of the samples macroscopic animals were found. Approximately 20 specimens were found in average per 1 litre sediment. The maximum number of 25 animal species (mean 5,8 species) was found in a single sample. Up to 150 cysts were determined in 1 cm^3 of tank sediment (Lenz *et al.* in prep).

4.2. Other than ship-mediated introduced nuisance species in the Nordic area

4.2.1. Intentional introductions

Several hundreds of species have been introduced to European terrestrial habitats in the past. The variety of these species ranges from protozoans, plants, insects and gastropods to vertebrates. Intensively studied introduced semi-aquatic species closely related to the coastal ecosystem in e.g. the inner Baltic Sea are the mink, the muskrat and the Canada goose.

American mink (*Mustela vison*) was deliberately introduced with severe negative impacts on native communities. Bird populations can be threatened by the predatory behaviour of the mink, feeding on the nesting sites. Recently, a drastic decrease of the sea bird population in the Stockholm archipelago has been observed, probably linked to the occurrence of the mink (HELCOM 1996, Williamson 1996).

The **muskrat** (*Ondatra zibethicus*), native to North America, was intentionally introduced to the Czech Republic in 1905 for purposes of fur trade. Other releases took place in Russia, Finland, France and the British Isles in the 1920s. The muskrat can live in fresh and salt-water habitats (marshes, ponds, lakes, streams and rivers). The species occurs in a wide variety of habitats more or less all over Europe (Williamson 1996).

The **Canada goose** (*Branta canadensis*) was introduced to Europe more than 150 years ago. Being in Europe for such a long time, it has become very numerous in the last decades, causing unwanted agricultural impacts. In some areas it might even have competed with native species. Negative effects caused by introduced species are often overlooked until the species occurs in high densities. Even little economic or ecological impacts may result in tremendous effects during mass occurrences (Williamson 1996).

The **king crab** (*Paralithodes camtschatica*) was intentionally introduced into the Russian area of the Barents Sea in the 1960s (Orlov & Ivanov 1978, Kuzmin *et al.* 1994). The purpose was to increase the harvest of local fisheries. Single individuals were caught occasionally. The first record of a king crab in Norwegian waters was documented for 1985 (Brattegard pers. comm.). But, since 1992, the crab has spread along the Norwegian coast and was found in the Varangerfjord causing problems to fishermen in the area, although others may benefit from the catches (Botnen, Wallentinus pers. comm.). Recent information indicates a rapid increase in the Varangerfjord and Murmansk region. Large single individuals found close to Tromsö and the Vesteraalen region document the spread of the species in Norwegian waters (Joerstad 1996, Hufthammer *et al.* 1997).

Escpecially in the 1950s and 1960s, many species (e.g: mysid shrimps) were intentionally introduced to lakes and water reservoirs in the Baltic area in order to guarantee a food source for commercially interesting fish species. Most of the introduced species came from the Ponto-Caspian region and several of them have been able to spread into some coastal lagoons (Gasiunas 1963, Kublickas & Bubinas 1985, Olenin & Leppäkoski 1999).

4.2.2. Unintentional introductions

The most important introducing vector for unintentional species introductions beside shipping is aquaculture. For example, more than 100 species have been documented as being transported with living oysters in the packing material, settling on the oyster shell or as parasites and disease agents in the oyster tissues (Bonnot 1935, Korringa 1951, Edwards 1976, Farnham 1980, Carlton 1992, Sindermann 1992, Minchin *et al.* 1993). Introduced salmonid fish have also been used for farming with the risk of escapes. Pleasure fishing is another vector, which often is neglected, resulting in release of both bait organisms and living packing materials such as seaweeds (Wallentinus pers. comm.).

The recent world-wide growth of aquaculture along major shipping routes amplifies this risk, possibly rendering disease regulations for this industry useless in many areas (Rosenthal 1980). Other human mediated vectors are the imports for scientific purposes and the removal of natural barriers e.g. due to connecting seas by man build canals (e.g. Welland Canal, Panama Canal, Suez Canal and Kiel Canal).

In addition to their contacts by straits with the Mediterranean and the Atlantic, the European brackish-water seas are connected to each other and adjacent bodies of water by canals and rivers. The Baltic and Black Seas became interconnected via the rivers Dnieper and Neman and Oginskij Canal, opened in the1780s. The Caspian Sea became connected with the Black and Azov Seas via the rivers Volga and Don by a canal opened in 1952. Opening this canal permitted the American invaders *Balanus improvisus*, *B. eburneus*, *Blackfordia virginica* and *Rhithropanopeus harrisii* (first found in 1957) among others, to penetrate into the Caspian Sea (Kasymov 1982).

4.2.3. Secondary spread within the invaded area

Successfully introduced nonnative species may effectively invade new habitats adjacent to the invaded sea area by natural dispersal via e.g. transport by water currents, as e.g. the Japanese seaweed, *Sargassum muticum*. The first Nordic findings of drifting specimens of this species were from the Limfjord, Denmark, in 1984 and in the adjacent Skagerrak. In 1987, the first attached algae were observed on the Swedish west coast (Wallentinus 1992). Furthermore, the species has extended its range to Nordhordaland (Norway) (Brattegard & Holthe 1997) (Box 7). Drifting pelagic larvae also contribute to the further dispersal of several macrofauna species.

Box 2

WHAT is a nonindigenous species?

Species found in a new habitat (outside their native range) have so far been described by different terms (exotic, alien, nonnative, nonindigenous, foreign, and invasive). The species must have been carried or migrated from their native range to the new area. This mechanism is described as human mediated (introduction, translocation, transplantation and transportation) or non-human mediated (migration, acclimatisation (adaptation) and colonisation) dispersal (see appendix for more definitions and references).

In the same way as the term of their status, there are different definitions to what a nonindigenous species is. The most common definitions used are

- "*Nonindigenous species*" (= alien or exotic species) Any species intentionally or accidentally transported and released by man into an environment outside its native range
- "*Introduction*" - the dispersal, by human agency, of a living organism outside its historically known range

5. Impacts of introduced nonindigenous species

All introduced species pose some impact (Box 3, 4 & 5). The scale of the impact varies from species to species or within different areas where a species has been introduced.

Box 3

IMPACTS of introduced nonindigenous species

Often the impacts of an introduced species are divided into threats and beneficial effects. This subdivision can be made after intensive and long-lasting studies of an introduced species in its new habitat. Most of the phenomena listed will be seen during mass occurrences of the introduced species. In the beginning one might think that the new species is an addition to the structural and functional diversity (defined as *xenodiversity*; Leppäkoski & Olenin, submitted), and therefore, it might be quoted as a beneficial impact. During mass occurrences this species may, in the worst case scenario, drive native species extinct.

The ecological worst case, the replacement of a native species caused by the exotic invader, can effect not "only" one single newly extinct native species but also any other organism dependent on it as a food source or habitat. As a result food web structure may intensively change after the introduction of one single species.

5.1. Ecology

Species introduced to a new environment may threaten native populations, fishing industries, aquaculture, water intakes of power plants and urban water supplies and public health etc. (Box 4 & 5). The likelihood of an introduced species to settle in new areas and to create problems depends on a number of factors. These are primarily related to the biological characteristics of the species and the environmental conditions to which the species has been introduced, incl. the properties of the invaded ecological community. Additional factors are climate, number of introduced specimens (size of founder population), native competitors and the availability of food as well as potential predators/grazers or disease agents.

Box 4

Threats / risks

Environment

- changes in resource competition (food, space, spawning areas)
- changes in habitat (chemical, such as use of biocides; physical, such as reduced water movements, and biological)
- limitation of resources (lack of oxygen)
- introduction of new functional groups and detrimental changes in the trophic web
- uncontrolled dispersal through unexpected ecophysiological response
- introduction of potentially toxin producing species (harmful algal blooms, some seaweeds)
- introduction of new disease agents or parasites (viruses, bacteria, fungi, ecto- and endoparasites) associated with an introduced host species. The nonnative host species might be immune, but native species are not. Huge amounts of disease agents might finally affect the introduced species.
- genetic effects on native species (hybridisation, change in gene pool, loss of native genotypes)
- extinction or drastic reduction of the population size of native species (also an economic impact, if the threatened native species has been a target species for e.g. the fishing industry or is an important food source for commercial species while the introduced one is avoided)
- introduction of a species being a missing link as host in the life cycle of a parasite

Economy

- effects on underwater constructions by fouling species (water intakes, boats), expensive cleaning procedures and the application of preventing measures (antifouling paint) needed
- tourism (mass accumulation on shores causing smell or sharp shells that has to be removed, or dense growth of plants in shallow bays used for swimming)
- loss in commercial or recreational fishing harvest, if the introduced species will affect target species
- losses in harvest of aquaculture
- cost of chemicals for eradication
- damage caused to marine archaeology, i.e., underwater heritage objects such as *e.g.* old sunken sailing vessels from the last centuries. Recently the shipworm *Teredo navalis* spread further eastwards in the southern Baltic Sea threatening wrecks off the German island Rügen (Gosselck pers. comm.).

5.2. Economy

The various potential threats caused by introduced species are listed in Box 4. The wide range of affected parties enforces the need for international and national co-operation between all stakeholders. Due to the lack of data it is not possible to estimate the economic costs caused by NIS in the Nordic Sea area.

In Australia a calculation was made to summarise all economic and social costs that could arise due to the unwanted introduction of toxic dinoflagellates and could be avoided by effective (95-99 % effectiveness) ballast water management. The calculation takes into account impacts on tourism, public health and aquaculture; it summarised to about A$ 200 million. The aquaculture component in this calculation consists of A$ 57 million (Acil Economics 1994).

The costs caused by the unintentional introduction of the zebra mussel (see below) has been estimated to 500 million US $ until the turn of he century. These include the removing of fouled mussels from water intakes of power plants, boats and port installations.

The ctenophore *Mnemiopsis leidyi* (see below) was first recorded in the Black Sea in 1982. Today the comb jelly is well established and changes the whole pelagic food chain. Recent mass occurrences of the comb jelly predating on fish larvae and the food organisms of fish, local overexploitation and increasing eutrophication resulted in a collapse of the anchovy fishing industry (see 15.3.4.) (Vinogradov *et al.*1989, Shushkina & Musayeva 1990, Reeve 1993, Zaitsev & Mamaev 1997).

Although we know of several ecological impacts of introduced species in the Nordic area it is not possible to give any figures on the economic impacts of nonnative species. In addition to the rich natural resources of the North Atlantic, it is important to note that also the Baltic Sea is a considerable source for commercial fishing on cod, flounder, sprat, herring, salmon and eel and in the Kattegat, prawns, shrimps and Norway lobsters.

The total catch of the fishing industry per Nordic country and world-wide in 1995, based on data of the FAO.

Country	**Catch (million tons)**
Norway	2.8
Denmark	2.0
Faeroe Islands	0.3
Iceland	1.6
Sweden	0.4
Finland, incl. Åland Islands	0.1
Total (Nordic countries)	**7.2**
World-wide	**84.0**

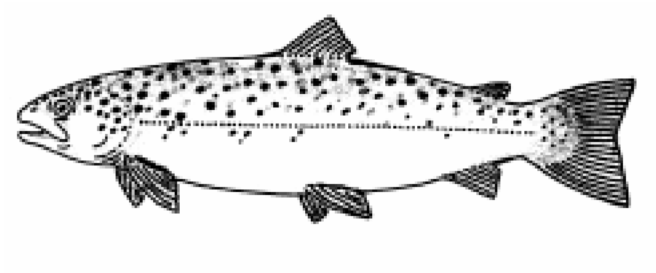
In order to document the need to protect the fishing grounds and to evaluate the magnitude of economic interest the following paragraphs list some key data on the commercial fishing in the Baltic Sea and Skagerrak.

5.2.1. Fish

The Swedish catch of cod (east of Bornholm) only varied between 150,000 tons and nearly 400,000 tons during the last decade with a decreasing tendency. In 1993, official reports list about 25,000 tons mainly due to bad recruitment caused by anoxic conditions in the depth with sufficient salinities. The total landings of flounder have remained stable over the last 20 years (HELCOM 1996).

Annual landings of sprat reached about 200,000 tons in the 1970s, decreasing to less than 50,000 tons in the beginning of the 1980s. In 1994 the annual sprat landings were documented to a maximum of 300,000 tons. Besides higher fishing effort this might also be caused by increased eutrophication and /or reduced predation.

The Swedish fishery fleet caught herring in the 1980s from nearly 150,000 tons to an annual maximum of more than 225,000 tons in 1984. Salmon catches (reared and wild salmon) in the Baltic Sea fishing nations are of commercial interest. In the 1980s the salmon catch was from >2,500 to 4,000 tons. In 1990 more than 5,500 tons of salmon were caught. Since 1990, salmon catches are decreasing (1994 about 3,000 tons), mainly due to the effect by the M 74 syndrome. The commercial catch of eels shows a decreasing trend. In 1955 about 7,000 tons were caught, in 1993 less than 2,000 tons (Wastenson *et al.* 1992, HELCOM 1996).



Oncorhynchus mykiss, the rainbow trout

5.2.2. Crayfish

In the western Baltic Sea, shrimp were caught more than 1,000 tons in each year in the 1980s. In 1986 more than 1,750 tons were caught. Norway lobsters (not occurring in the Baltic proper) have been caught in 800 to 2,000 tons annually over the last 20 years.

5.2.3. Aquaculture

Aquaculture in the Baltic Sea area is mainly based on rainbow trout, salmon and eel. In 1996, the world production of aquaculture (total, incl. freshwater) was approx. 26 million tons.

Aquaculture production in the Nordic countries and world-wide production in 1996.

Country	Production (tons)
Norway	334 100
Denmark	41 400
Faeroe Islands	17 600
Iceland	3 700
Sweden	8 300
Finland	11 900
Åland Islands	5 700
Total (Nordic countries)	**422 700**
World-wide	**11 300 000**

In addition to the potential economic danger to the fishing industry, due to introduced disease agents, parasites or predator species preying upon fish and crayfish larvae, the fish processing industry could be negatively effected. Negative effects on pleasure fishing and thereby the tourist industry can occur as well (Wastenson *et al.* 1992). NIS can interfere with fisheries, by reducing the quality of fish for human consumption (diseases, algal toxins), and fish production by influencing the food web of commercial fish species, e.g. dead-end organisms such as *Mnemiopsis*, *Marenzelleria* and *Balanus* that are hardly consumed by fish.

The Australian Bio-Economic Risk Assessment report from 1994 estimated that costs of US $ 292.5 million of damages in regard to tourism, public health and aquaculture could be avoided by the application of effective ballast water treatment (ACIL Economics 1994). Until today this has been the only report listing costs on what may be saved by the implementation of treatment, resulting in the minimisation of potentially harmful species introductions.

Box 5

Benefits / advantages

Environment

- stock enhancement (robust species have been intentionally added in polluted waters to prevent interruption in the food web)
- additional food source for native species
- most invasions initially lead to an increased local biodiversity (also for economy, in case of a new profitable target species for e.g. fishing industry)
- deep digging animals may increase bioturbation and thereby oxygen availability and provide better conditions for denitrification
- species with high filtering capacity increase water clearance
- provide shelter or settling substrate (e.g. on shells, plants especially on barren sediments)
- prevent erosion (e.g. plant rhizoms in intertidal areas)
- decrease numbers of previous introductions (e.g. biocontrol)

Economy

- improved fishery harvest of wild catches or aquaculture
    - total amount
    - extension of fishing season
    - better quality of harvest
- increase of employment
- management of coastal areas

6. Case histories of intensively studied brackish water areas

6.1. The San Francisco Bay example

Nonindigenous aquatic animals and plants impact the ecology of the San Francisco Bay area. Presently, no shallow water habitat remains uninvaded by exotic species and it is difficult to find abundant native species locally. In some areas of the Bay, 100 % of the common species are introduced, creating "introduced communities". In locations ranging from freshwater sites in the Delta, through Suisun and San Pablo Bays and the shallower parts of the Central Bay to the South Bay, introduced species account for the majority of the species diversity (Cohen & Carlton 1995).

Nonindigenous species dominate many of the food webs. NIS are abundant and dominant throughout the benthic and fouling communities of San Francisco Bay. The filter feeding activity of introduced clams results in the failure of the summer diatom bloom in the northern area of the estuary. The linkages between introduced and native species may provide a remarkable example of the potential impact of an introduced species on the estuary's food webs.

Benefits derived from accidental introductions to the estuary are due to the commercial harvests of introduced mussels (*Mya*, *Venerupis* and *Corbicula*), crayfish (*Pacifastacus*) and fish (Asian yellowfin goby is commercially harvested for bait). However, a single introduced organism, the shipworm *Teredo navalis,* caused $615 million of structural damage to maritime facilities in three years in the early 1900s. The economic impacts of hull and other ship fouling are clearly very large, but are not documented or quantified. Most of the fouling incurred in the San Francisco Bay area is caused by NIS.

It is supposed that the greatest economic impacts may derive from the destabilization of the estuary's ecosystem due to the introduction and establishment of a new species every 24 weeks (in average) (Cohen & Carlton 1995, 1998).

6.2. The Black Sea example

Rivers and manmade canals connect the Black Sea and the Baltic Sea with each other. Species introductions by shipping have resulted in major changes of coastal habitats in both seas. Unintentional species introductions are among the most remarkable anthropogenic influences on the Black Sea ecosystems (Zaitsev & Mamaev 1997).

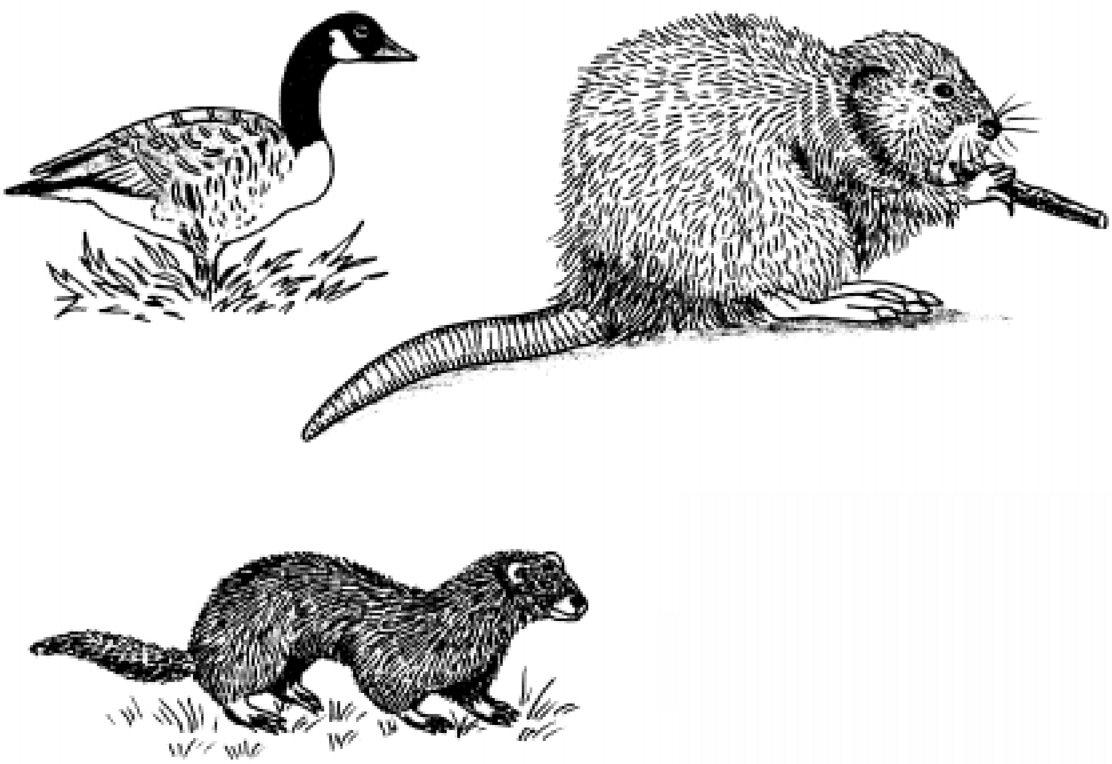
The Black and the Baltic Seas are large enclosed brackish water bodies with many similar environments, biota and problems (Leppäkoski & Mihnea 1996). Both seas belong to the east Atlantic boreal climate zone. Furthermore, the salinity gradient of the Black Sea is comparable to the Baltic Sea. In the Black Sea the salinity changes from more than 30 PSU in the water body strongly influenced by the Mediterranean Sea to 2 - 5 PSU in the Sea of Azov. The salinity of the greatest part of the Black Sea is 18 PSU, of the Baltic Sea 8 PSU. In the same way as the Baltic Sea, the Black Sea provides a wide variety of habitats. At least 35 species are known to have been introduced to the Black Sea; several (16) of these also occur in the Baltic Sea. Some recently introduced species became nuisance organisms threatening the economy and ecology of the Black Sea. The occurrence of the introduced soft shell clam *Mya arenaria* (first recorded in 1966) resulted in tons of decaying and stinking specimens washed ashore in some tourist resort areas. The mussels had to be removed from the beach every morning during the summer season to avoid disturbing the tourists. The Japanese predatory snail *Rapana thomasiana* occurs in great numbers as well, and it affects mussel beds. The commercially harvested oyster beds of the Caucasian coast were nearly completely destroyed. In the 1980s the fishing industry began to harvest on the introduced snail for human consumption. In addition, severe negative effects were recorded from blue mussel beds (Zaitsev & Mamaev 1997).

6.3. Coastal inlets of the Baltic Sea

The semi-enclosed water bodies of the Southern (Curonian and Vistula lagoons) and Northern Baltic (inner Archipelago Sea and Northern Quark, Gulf of Bothnia) differ by their origin and present environment, scope of anthropogenic impact and level of euthrophication. These areas presently host at least 18 non-native species of benthic invertebrates. The ecological role of these species has recently been evaluated in terms of: a) their relative abundance and biomass in bottom communities; b) their feeding/mobility status and their ability to alter the physical and chemical environment of the ecosystems they invaded; c) vacancy/occupancy of the niches before these species have been introduced (Olenin & Leppäkoski 1999).

The NIS have significantly altered ecosystems of the SE Baltic coastal lagoons, while their role in the northern coastal waters is still much less important. Some habitats, e.g., secondary hard bottoms (underwater constructions) seem to be rather open everywhere to alien fouling organisms. Here *Balanus* and *Dreissena* increase the area and volume available for associated macro and meiofauna, and enhance detritus-based food chains by supplying their habitat with particulate detritus. *Marenzelleria* digs deeper than most native species can do, thus increasing the thickness of the populated surface sediment layer and depth limit of bioturbation. Shell deposits of *Dreissena* in the Curonian Lagoon have changed former soft bottoms (sand or silt) into shell gravel, and created patches of hard substrate for sessile species on uniform soft bottoms on sites. *Mya* shells form a secondary hard substrate available for associated species. Empty shells of the barnacle *B. improvisus* serve as new microhabitats for small annelids, crustaceans and chironomids. Microscale habitat alterations are known to facilitate colonisation of substrate-specific species (CARLTON 1996).

The alterations described above seem to be more pronounced in the SE Baltic lagoons compared to the N Baltic coastal inlets. Their susceptibility to invasions (as summarised by Olenin & Leppäkoski 1999) may be due to (1) their topography (e.g. uniformity over large areas, i.e., low habitat diversity), (2) their repeated early successional status subsequent to stochastic changes of abiotic environmental factors (fluctuations, and especially sudden salinity fluctuations in the lagoons as a key factor; unstable ecosystems have been postulated to be more open for nonnative species than stable ones) (3) their low number of native species, (4) environmental changes in these recipient regions (e.g., increasing eutrophication or other disturbance) or (5) stochastic inoculation events (e.g., intentional introductions to nearby freshwater reservoirs in the Baltic republics of the former USSR).



Semi-aquatic invertebrates native to North America

Branta canadensis, the Canada goose

Ondatra zibethica, the muskrat

Mustela vison, the North American mink

7. Predictions

It is not possible to indicate whether an ecological system will be open or resistant to invasions (Williamson 1996). In addition, human mediated accidental introductions are believed to be unpredictable (Zaitsev & Mamaev 1997). During controversial scientific discussions it has been agreed that all ecological communities are in general invasible.

The number of NIS recorded in different coastal waters is significantly different, varying from less than 25 introduced species to more than 200 in other areas (Ben-Tuvia 1953, Rubinoff 1968, Ben-Eliahu 1972, Walford & Wicklung 1973, Farnham 1980, Krapp & Sconfietti 1983, Leppäkoski 1984, 1994, Knudsen 1989, Zibrowius 1991, Boudouresque *et al.* 1992, Utting & Spencer 1992, Galil 1994, Jansson 1994, Carlton & Cohen 1995, Gollasch 1996, Eno *et al* 1997, Minchin 1997, Ruiz *et al.* 1997, Zaitsev & Mamaev 1997, Lodge *et al.* 1998). Therefore, it seems obvious that certain communities are more open to introductions than others.

Serious predictions on the risk to receive further invasions and their potential impact on native economy and ecology needs long-term surveys (Zaitsev & Mamaev 1997, Lodge *et al.* 1998). Since the beginning of the 1990s, Australian and North American working groups have been involved in this research. Until today it has not been possible to predict exactly which organism will survive and establish in the new habitat. The reason for this unsatisfactory trial is the enormous number of factors which needs to be taken into account (e.g. minimum number of founder generation, climate, salinity, habitat structure, food availability and predators) (Acil Economics 1994, Hayes 1997, see also Chapter 15). Furthermore, it is difficult to predict the timing of future species introductions.

Some characteristics of invading species are known to be in common in successful invaders (Box 6). The limiting factor for most of the successful invaders is their flexibility in regard to temperature and salinity tolerance, habitat selection and food. However, there are physiological limits, even for the most opportunistic species. Hence species from similar latitude, i.e. similar climate, and similar water bodies in respect of salinity will have a greater chance for establishment once introduced.

Box 6

WHICH species will arrive and become a successful invader?

Several species show a high potential to invade areas outside their native ranges. Many of them are characterised by:

- high abundance in native habitat (Carlton *et al.* 1995)
- ability to survive the introducing process (conditions of vector and transport) (Gollasch 1996)
- wide range of habitat selection (Arthington & Mitchell 1986)
- high tolerance to abiotic factors, especially temperature and salinity (Williamson 1996)
- non-specificity in their food preferences (Carlton *et al.* 1995, Gollasch 1996)
- high rate of reproduction, r-selection (Arthington & Mitchell 1986, Williamson 1989) or a combination of r- and K-strategies (Farnham 1997)
- fast vegetative growth rate (Farnham 1997)
- growth earlier in season than native species (Farnham 1997)
- potential to occupy an "ecological niche", microhabitat or functional role (Crawley 1986, 1989, Olenin & Leppäkoski 1999)
- known as invader to other areas (Carlton *et al.* 1995, Gollasch 1996)
- high potential to replace native species (Howarth 1981, Holdgate 1986)
- long-lasting larval stage as a part of the life cycle (Gollasch 1996)
- ability to produce resting stages (cysts, dormant cells, buds) (Hallegraeff & Bolch 1992)
- vegetative or hermaphroditic reproduction (founder population might be a single specimen) (Lenz *et al.* in prep.)
- high ability to entangle or attach themselves (Wallentinus pers. comm.)
- drifting species (e.g. algae) have a high ability as secondary invaders (Wallentinus pers. comm.)
- resistant to grazers/predators in native area (Wallentinus pers. comm.)

To survive in a recipient area is a substantial, but only the first step. Secondly the newly introduced specimens need to reproduce effectively enough to become a successful founder population. Therefore, a minimum number of specimen as founder population is needed.

Not all species characterised by the features mentioned in Box 6 will become introduced and established: the receiving habitat and its biological and environmental conditions are limiting factors for a great number of introduced species. Additionally, the ability to survive the introducing process, especially the conditions provided by transporting vector, and the time of transportation are limiting factors (Gollasch 1996).

8. Vectors

The dominant vectors mentioned for species introductions are shipping (unintentional introductions via ballast water, tank sediments and hull fouling) and aquaculture (intentionally introduced nonnative target species and unintentionally introduced non-target species) (Box 7). For many species the introducing vector is unknown, but e.g. aquaria and pleasure fishing (bait and gear) are known to have provided additional routes for intentional and unintentional species introductions (Jansson 1994, Swedish Environmental Protection Agency 1997).

Box 7

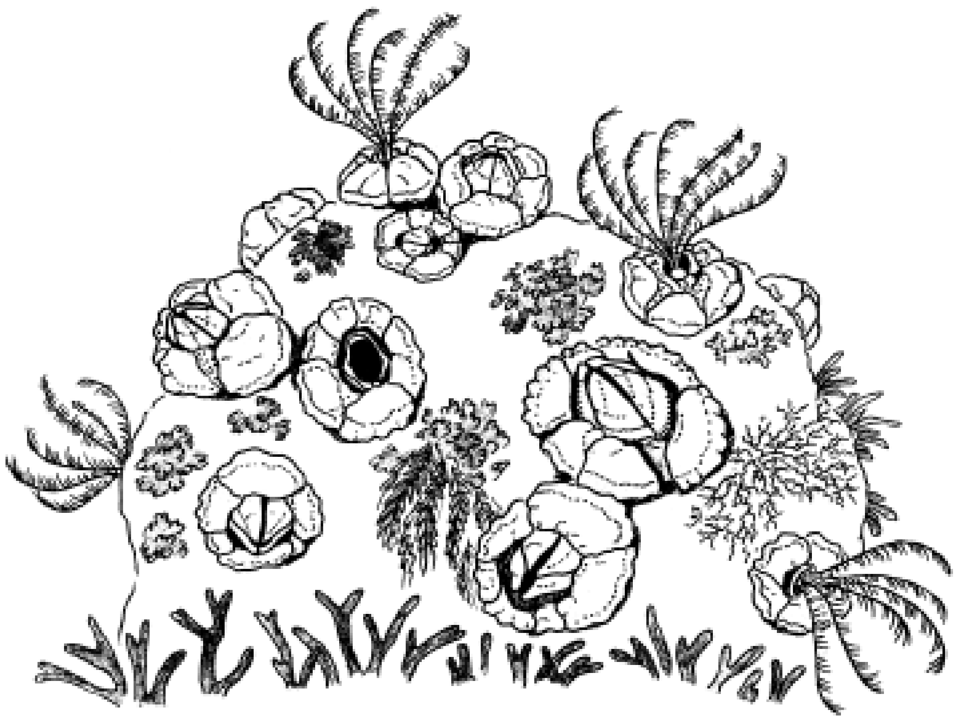
HOW did they come?

This list of main vectors for species introductions represents a tentative ranking according to their importance of introductions in the past:

- ships, unintentional introductions with ballast water, hull fouling, sediments in ballast tanks and sediments attached to anchors and anchor chains and chain locker water
- aquaculture, intentional (target species) and unintentional introductions (non-target species as e.g. epi- and endobionts as well as parasites and disease agents)
- stock enhancement purposes
- removal of barriers (as e.g. openings of canals) supports natural migration
- usage of living organisms as baits or packing material for baits
- ornamental trade, imports for hobby or public aquaria
- fish processing companies often discharge unusable material of imported live specimens, potentially containing parasites in the wild
- research, accidental "escapes" or intentional releases after experiments
- remaining organisms in fish nets and traps
- on or within equipment used for recreation (e.g. diving bags, boats)
- import of live animals for human consumption accidentally released into the wild before marketing
- ocean and coastal currents (organisms attached to man-made floating objects)
- species introduction as fouling organisms to migrating nonnative host species as e.g. birds or fish
- transport of sand and gravel as construction material

Nordic sea areas become first infested with nonnative species transported on ships seven centuries ago by the Vikings (Petersen *et al.* 1992). Some species (e.g. wood boring organisms) were introduced a long time ago with wooden sailing vessels. There are also examples from the Baltic Sea of aquatic organisms such as *Chara connivens* (Luther 1979) introduced via dumped solid ballast in the 19th century. Improvement of ship design prevents the introduction of the adult species today, but larvae, plankton and resting spores can be transported in the ballast water.

Furthermore, environmental changes in donor areas, recipient areas and dispersal vectors as well as new donor areas (due to changing traffic routes) will enforce the world-wide transport of NIS.



Balanus improvisus, the barnacle

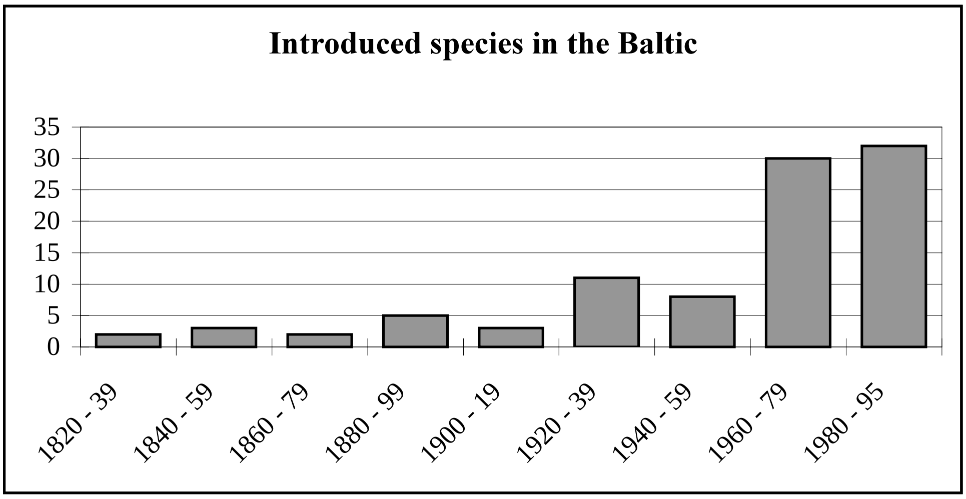
9. Timing - when did they arrive?

Theoretically a species will be successfully introduced if all abiotic and biotic factors are tolerable. This theory is called the "Window of introduction theory" (Carlton *et al.* 1995). The theory takes into account that there are 10 possible moments in a decade, when all the mentioned conditions are desirable for one single species and this species has to be released in the new environment in sufficient numbers at exactly this time to become established. However, until today, we cannot predict when all these conditions coincide and a window of introduction would be opened.

The number of NIS in the Baltic Sea has increased during the last 30 to 40 years (Box 8).

Box 8

WHEN did they arrive?



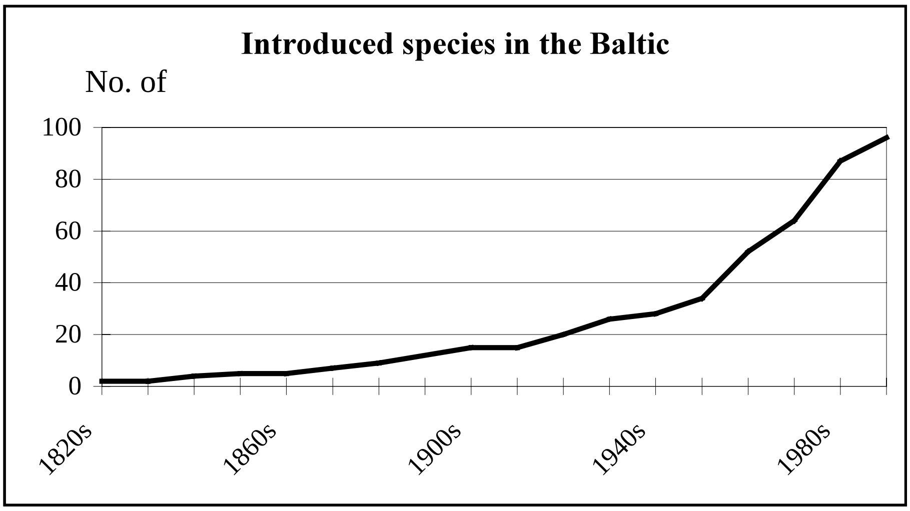
Numbers of nonindigenous species first recorded in the Baltic Sea within 20 year intervals starting with 1820 (n = 96 species, established and non-established species included). Last updated 1995 (Gollasch 1996). The column for 1980-1995 is incomplete, as documented and proven records usually appear years after.

During the German ship sampling programme (see above) a desk study on introduced NIS in German waters was carried out. In total 170 NIS were found during the last 100 years. In average 1,7 species were recorded per year or every 28 weeks a new record of a NIS was made. Both established and non-established (occasional findings) of NIS were included in this estimation.

Until today 212 species have been introduced to the San Francisco Bay area. Since 1850 an average of 1 new species was documented every 36 weeks. Since 1970, one new species has been recorded every 24 weeks (Cohen & Carlton 1995).

Box 9

Cumulative numbers of first records of nonindigenous species in the Baltic Sea



The figure documents the total number of established and non-established nonindigenous species found in the Baltic Sea since the 1820s cumulatively (n = 96 species). Last updated 1995 (Gollasch 1996).

Reasons for the increasing numbers of first records since the 1950s

Technical improvements of the main vector of species (ships) are responsible for the increasing number of introduced species since the 1950s. The new generation ships are faster and bigger than a couple of decades ago and the total number of ships registered world-wide is still slightly increasing. This results in an increasing number of ship visits discharging an increasing amount of ballast water. The probability of the introduction of an aquatic species becomes higher due to the shorter period the organisms need to survive in the special (critical) conditions inside the ballast tanks during a voyage. Several studies have shown that with a decreasing voyage time the number of species and specimens surviving these voyages increases (Carlton unpubl. data, Rigby & Hallegraeff 1993, 1994, Fukuyo *et al.* 1995, Lenz *et al.* 1995, Gollasch 1996). In addition, the multiple introductions due to an increased number of ship visits increases the probability of introducing NIS (Box 10).

Box 10

WHY do they arrive now?

- technical improvements of ships as the main introducing vector result in faster and bigger vessels than a couple of decades ago
- shorter duration inside the ballast tank during a voyage increases the survival rate
- increasing number of ship visits
- discharging an increasing amount of ballast water
- increasing ship trade enforced to build new ports causing additional or new species introductions
- cleaner ballast water
- better water conditions in area of uptake with increased number of species to be exported
- increasing probability of multiple introductions

Window of introduction theory. The theory takes into account that all needed conditions have to be desirable for the successful species introduction.

10. Establishment of introduced species

10.1. Long term establishment

Some species have been introduced once and were able to establish a self-reproducing population. Other species of animals and plants have been introduced several times and failed (Box 11). The success of establishment depends on several factors previously discussed (Box 6 & 10). Species that failed in their establishment in the Nordic area are e.g. the Chinese mitten crab and the horse shoe crab. On the other hand, there are examples of species that became extinct after decades of occurrence.

Box 11

ARE they here to stay?

YES, it is assumed that species, which were able to create self-reproducing populations since several generations, will continue to stay in the Nordic sea areas.

BUT, not all of the recorded nonindigenous species established self sustaining populations over a longer period of time. Hindering factors are, among others, the hydroclimate and the size of the founder population:

- the cold winter temperature conditions and low salinity in the Baltic Sea may limit the survival rate of invaders from warmer or more marine donor areas.
- species of which only occasional findings are recorded are believed to be introduced in a very small number of specimens. Meeting a partner for reproduction is in this case unlikely, unless they are able to reproduce asexually or are hermaphroditic/monoic species.

10.2. Failed establishment in the Nordic waters

10.2.1. Chinese mitten crab

Specimens of the Chinese mitten crab *(Eriocheir sinensis*), introduced to Germany in 1912, are found several times annually in the Baltic Sea but do not indicate an established population. To complete its life cycle this species needs to migrate into marine waters. In its native habitat (China) specimens have been found in rivers more than 1,400 km upstream. The specimens found in the Baltic Sea belong to the established populations in rivers adjacent to the North Sea. It is today present in diluted coastal waters from the Gulf of Bothnia to the Swedish west coast (Hansson 1993). From the Swedish Kattegat coast there have also been records from fjord areas, where the salinities may be high enough for breeding.

10.2.2. Horse shoe crab

Sporadic findings (a couple of records per decade) of the horse shoe crab (*Limulus polyphemus*) prove that the species has the potential to become introduced to Europe. In its native habitat, the North American east coast from Cape Cod to Florida, temperature conditions are comparable to the Baltic Sea. The horse shoe crab can be found in estuaries and marine waters; main distribution areas are the Delaware Bay and Chesapeake Bay estuaries. Therefore, it is assumed that the climate and salinity will not be the excluding factors. The very few individuals found in Nordic waters (Baltic and North Sea shores of Denmark) indicate that the number of species is too small to create a successful founder population (Wolff 1977).

10.2.3. Blue crab

The number of findings of the North American blue crab *Callinectes sapidus* in the Baltic Sea are even more rare than the records of the horse shoe crab. Several findings were mentioned in non-scientific journals, but the only scientifically proven record is from 1951. The species was found north east of Copenhagen (den Hartog & Holthuis 1951, Holthuis 1969). The species is native to the North American east coast from Cape Cod to Florida and Texas. It occurs in estuaries and marine waters (Kühl 1965).

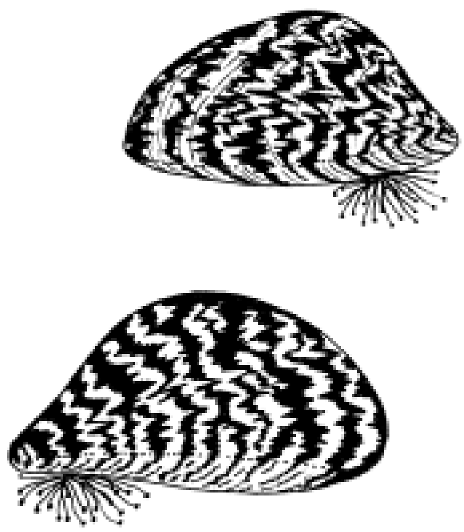
10.3. Once established and now extinct or rare

The cnidarian *Haliplanella lineata* became established on the west coast of Germany in the 1920s. The species was present for at least two decades and thereafter disappeared completely. Due to the absence of a predator, the reason for this "extinction" was unclear for a long time. The most probable explanation could be derived from its reproduction cycle. In German waters the species was only able to reproduce asexually. Therefore, all specimens consist of an identical genome (clone). It is believed that once only one abiotic factor changed and that made the entire population intolerable to this disturbance due to the lack of genetic variability.

In the 19th century the charophyte *Chara connivens* became established at several ballast dumping sites around the Baltic Sea (Luther 1979). Like many other charophytes it has been largely reduced in abundance and now appears on the Swedish “red list” as vulnerable (Blindgaard 1996). This is probably caused by a combination of eutrophication and habitat destruction of shallow bays.

10.4. The 10’s rule

Scientists have tried to mathematically cover the rate of possible introductions. Darwin (1900) estimated that 5 % and Williamson (1989) 10 % of the introduced species are creating established populations for at least several generations. About 10 % of all introduced and established species will occur in high or massive densities. This 10´s rule was mainly based on introductions to terrestrial habitats (Holdgate 1986, Simberloff 1986, 1989, Williamson & Brown 1986). Williamson (1996) revised the 10´s rule pointing out that "10" ranges from 5 to 20. It is quite unclear if this rule can be applied for aquatic ecosystems as well. Furthermore, it has to be taken into account that one single introduced species can cause severe damage to economy or environment as the zebra mussel shows in the North American Great lakes and the coastal inlets of the Baltic Sea and the comb jelly in the Black Sea.



Dreissena polymorpha, the zebra mussel

11. Are there special areas attracting invasions?

As known from different sites around the globe invaders are common in disturbed areas. Recently introduced species are often rare or less important in undisturbed pristine communities. The San Francisco Bay is an excellent example. Until today 212 NIS have been introduced to the area. Other communities with comparable climate, salinity, topography and habitat structure were invaded by far less species (Cohen & Carlton 1995).

Box 12

WHERE are further introductions going to happen?

Areas with a high potential to receive further introduction (hot spot areas) are characterised by:

- matching climate, salinity and habitat structure (Carlton *et al.* 1995, Gollasch 1996)
- "ecological niche" (microhabitat) available (Elton 1958, Crawley 1986, 1989)
- absence of predators, grazers and/or parasites in recipient area (Arthington & Mitchell 1986, Williamson 1989, Wallentinus pers. comm.)
- strong anthropogenic influence (pollution, power plants, aquaculture, artificial hard substrates) (Nichols & Pamatmat 1988, Leppäkoski 1984, 1991)
- low number of native species (Elton 1958, Wilson 1965, Briggs 1966, 1974, Magnuson 1976, Vermeij 1991, 1996)
- embayments and estuaries are probably more open for invasions than habitats of the outer coast as the studies on the San Francisco Bay, Chesapeake Bay and the Curonian Lagoon (SE Baltic Sea) indicate (Cohen & Carlton 1995, Ruiz *et al.* 1997, Olenin & Leppäkoski 1999).

Future introductions may predominately occur in (Box 12):

- port areas, due to the comparably high pollution and large volume of discharged ballast water
- estuarine areas that appear to be more open for invasions
- along major shipping routes of international traffic, due to high amount of introduced ballast water
- the vicinity of power plants, due to elevated water temperature providing tolerable conditions for invaders from warmer climates (e.g., the polychaete *Ficopomatus enigmaticus* in the Ems Estuary and in the harbour of Copenhagen (Rasmussen 1958)

Keeping in mind the facts listed above it is estimated that some hot spot areas of the Baltic Sea and other Nordic seas will be more open for future introductions than others. These areas are mainly characterised by anthropogenic influence (Box 13).

Box 13

HOT SPOT AREAS along the Nordic coasts

High risk areas are

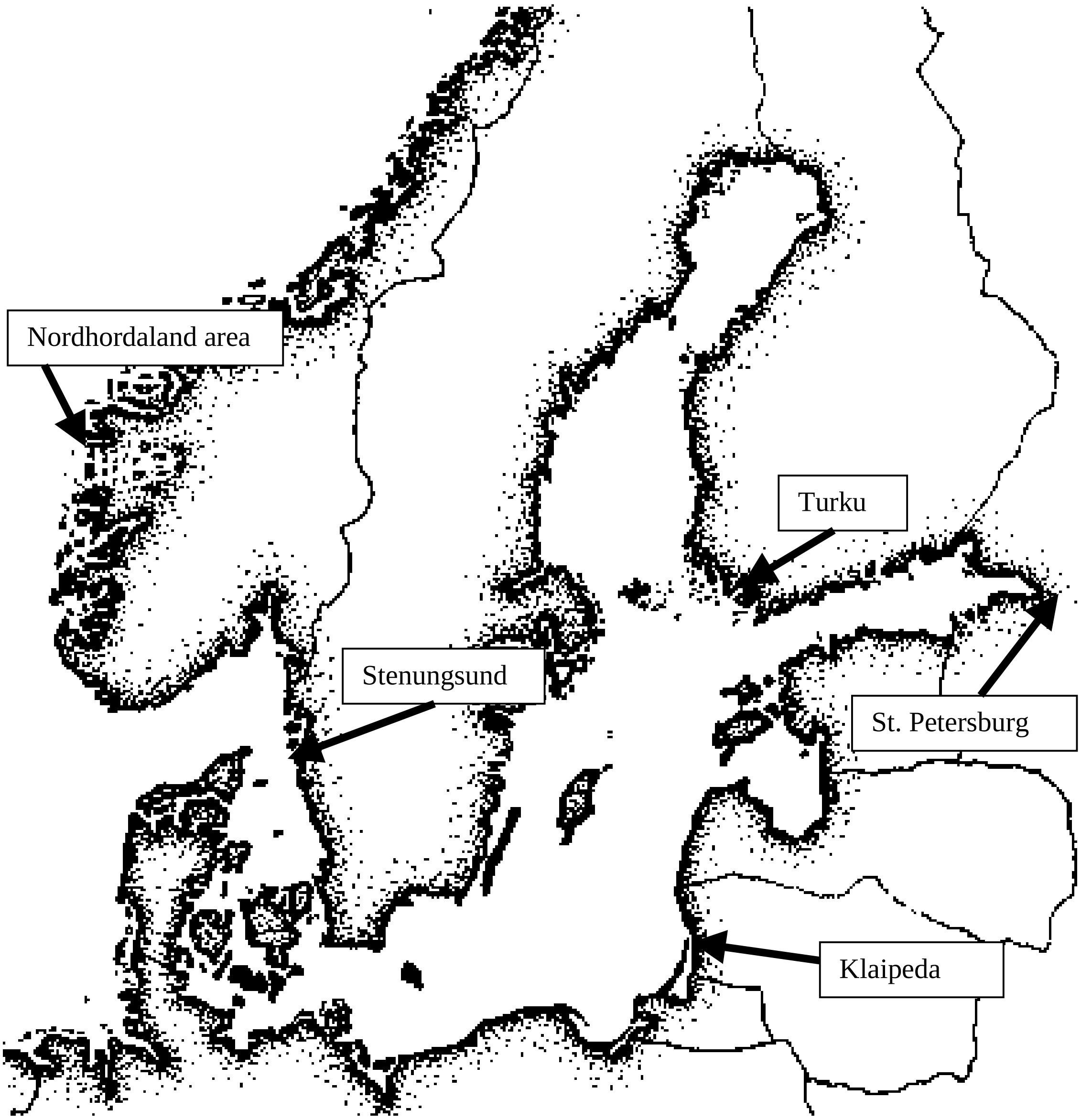
- ports and waterways
    - quays due to released ballast water
    - dockyards due to complete emptying of ballast tanks including sediment and cleaning of hull fouling during inspection of vessels and renewing the antifouling paints
- major shipping routes due to frequent ballast water release
- power plants, due to the increase of water temperature of the environment with cooling water and in this way enabling the establishment of warm-temperate species. After adaptation these species have the potential to spread
- designated zones for ballast water exchange due to frequent ballast water release
- heavily polluted regions (influenced by urban and/or industrial areas) cause negative effects on native species whereas tolerant nonindigenous species may be able to colonise the area
- aquaculture sites due to non-compliance of quarantine regulations, and therefore introduction of non-target species or accidental releases of target species
- estuaries of rivers connected with other watersheds by canals

12. Summary of port profiles

The port profiles of 13 ports have been described. Ports that are included in the detailed risk assessment study are typed in bold letters. The compared ports according to data available in the attached port profiles are (listed from west to east): Sture, Bergen, Eikefet, Ågotnes, and Mongstad (Norway, **Nordhordaland region**), **Stenungsund**, Vattenfall, Uddevalla and other local company owned ports (Sweden), **Klaipeda** (Lithuania), **Turku**, Naantali and Pargas (Finland) and **St**. **Petersburg** (Russia). In order to simplify the reading the ports of the Stenungsund area are summarised and will be mentioned below as Stenungsund. In the same way the Norwegian ports were listed below as ports of the Nordhordaland region.

12.1. Ports

In general the chosen port areas are largely varying and therefore represent different types of habitats of the Nordic coasts. Beside the Baltic Sea ports (Klaipeda, Turku and St. Petersburg) Stenungssund, slightly outside the Kattegat border and the North Sea ports of Nordhordaland are included (see map below). All ports selected belong to the major ports in each country.



12.2. Habitat structure

The habitat of the ports varies from hard bottom areas (Nordhordaland, Stenungsund) to soft bottom (Turku, Klaipeda and St. Petersburg).

In Norway a typical coastline includes fjords. A fjord can be regarded as a complex estuary connected to the coastal water with one or more sills. The water areas of Stenungsund and Turku are characterised by narrow sounds and shallow inlets. The port of Klaipeda is characterised by its unique location at the mouth of the Curonian Lagoon representing an estuarine-like habitat as at the port of St. Petersburg with the inflow from the Neva river.

12.3. Abiotic conditions of surface water

12.3.1. Salinity

With the exception of Nordhordaland and the Stenungsund area, all other ports are influenced by major freshwater discharges from rivers and are therefore brackish water habitats with salinities lower than 10 PSU. The Sture terminal with salinities around 30 PSU represents nearly ocean water conditions. In Sweden the salinity variation along the coast is high ranging about 25-30 PSU at the Skagerrak/Kattegat to less than 6 PSU in the waters along the Swedish east coast. Prevailing salinities in the Stenungsund area range from 20 to 28 PSU.

The salinity conditions of the port of St. Petersburg (0.1 PSU) are comparable with freshwater conditions.

12.3.2. Temperature

Summer

In all ports, the summer surface temperature can be > 15 °C. In the very shallow waters off Turku and Klaipeda the summer temperature even reaches 20 °C or more (up to 24 °C in the Curonian Lagoon near Klaipeda).

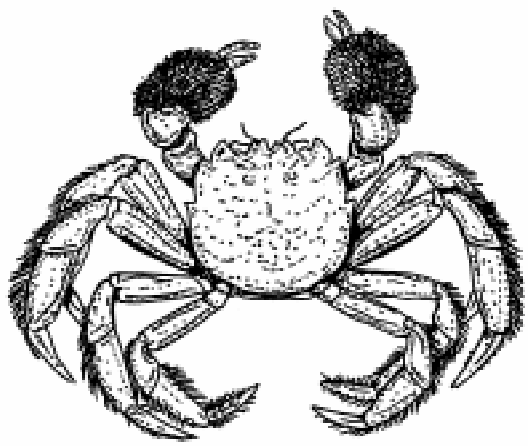
Winter

Apart from Klaipeda and the Nordhordaland region, all ports studied are characterised by temporary ice cover. At Stenungsund the ice cover is not a limiting factor for the shipping. In St. Petersburg and Turku a permanent ice cover occurs every year for several months. The number of "ice-days" varied in the last decade from 41 to 121 (Turku). In Klaipeda no ice cover occurs in the port area.

12.4. Ships' traffic

Ships from totally about 50 countries world-wide call for the ports compared. The number of annual cargo ship visits range from several hundreds (Sture, Turku) to more than 7,000 (Klaipeda).

The shipping statistics revealed that the main traffic routes are regional, i.e. mostly between Nordic countries or neighbouring states (i.e. Estonia, Germany, Latvia, Lithuania, Poland and Russia). Predominant traffic routes outside the Baltic Sea call for ports at the Black Sea, North Sea (U.K., Ireland, Germany and The Netherlands). Very few ship visits were on trading routes to north western Africa, the North American east coast, the Mediterranean Sea and Asia. Less than 5 % of the vessels calling for Sture and Stenungsund are from other areas outside the Nordic countries, Europe and North America.



Eriocheir sinensis, the Chinese mitten crab

13. Volume of ballast water discharged

13.1. Nordic countries

Data from Norway is available from two ports (Sture and Mongstad) only: 20.7 million tons of ballast water (15 % of non-European origin) is discharged annually in (Botnen pers. comm.).

Apart from the brackish coastal environments in Sweden, pure freshwater environments also receive international shipping. Some of these Swedish lakes serve as sources of drinking water, therefore, ballast water input to these areas should be of particular interest from a human health perspective.

Ballast water discharged from non-tankers in Swedish waters make up about two thirds (15.6 million m^3) of the total quantity discharged every year. Tankers account for a discharge of about 7.6 million m^3. It was indicated that 79 % of the international calls by tankers and 53 % of those by non-tankers discharge ballast water. Tankers discharge on average 2,272 m^3 and non-tankers 1,634 m^3.

The total quantity of ballast water discharged from ships in international traffic into Swedish coastal and inland waters is about 23 million m^3 per year. The largest quantities are of Baltic Sea and North Sea origin. Similarly most of the ballast water loaded in Swedish waters is transported to other Swedish water areas or, mainly, to the south-eastern part of the Baltic Sea (Estonia, Latvia, Lithuania, Poland and Russia).

From a Swedish perspective, the need for regional European co-operation is addressed to identify the risks associated with the release of alien species in ballast water. Studies conducted in several other European countries (Germany, Ireland, Norway, the U.K) demonstrate a similar pattern to that of the Swedish study: large local or regional transport of ballast water and a smaller input from outside north western Europe.

13.2. Europe

Ballast water discharges per year in English and Welsh ports amount to 16.8 million tons (Laing 1995) and in Scottish ports to 25.7 million tons (Macdonald 1994). About 10 - 15 % of the discharged ballast water originated from outside Europe. In Ireland less than 2 million tons were discharged, most of it from Europe (Minchin & Sheehan 1996). The estimations of the amount of ballast water in German ports and waterways varied from 8 to 38 million tons, of which 1.4 to 7 million tons were of non-European origin (Golchert pers. comm., Gollasch 1996).

13.3. North America

In 226 US ports (including the Great Lakes) in total 79 million tons of ballast water were dumped from vessels from abroad (Carlton 1995, Carlton *et al.* 1995). Gauthier & Steel (1995) estimated that 62 million tons of ballast water was discharged. It has been estimated that 12 million tons of ballast water is discharged annually in the estuary and Gulf of St. Lawrence. About 1.6 million tons originate from the last port of call of areas in Northeast Atlantic and the Mediterranean and Black Seas.

13.4. South Africa

Information on ballast water discharges was collected from several ports around the South African coastline. The estimation summarised relevant data from 1991/1992 to more than 12 million tons. Data from some ports is missing. It is likely that one of these (Port Elisabeth) receives about 20 million tons of ballast water each year. Roughly a third of this volume originates from Far East. A relatively high percentage of the water is exchanged en route, as a result of controls introduced in many ports of the world (Jackson in prep.).

13.5. Australia

Vessels calling for Australian ports discharge approx. 121 million tons of ballast water each year (Jones 1991, Mills 1992, O´Reilly 1992, Paterson 1992, Kerr 1994, MEPC35/INF.19). In addition, over 4,000 vessels per year move more than 34 million tons of ballast water between Australian ports.

13.6. New Zealand

The total amount of discharged ballast water, mostly of Asian origin, was estimated to 4.5 to 4.7 million tons each year (Hayden 1995).

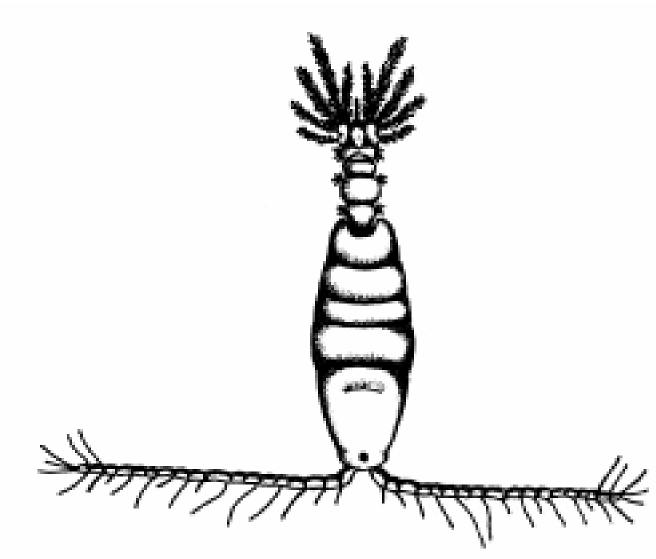
13.7. Résumé

The amount of discharged ballast water has been estimated in several ballast water studies around the world. However, one has to take into account that each single vessel has the potential to introduce one or several NIS. Therefore, not only the amount of ballast water is important to consider, but also the amount of species in this water. The volume of water from overseas origin released is an indicator of the potential for further species introductions.

14. Effects of eutrophication

Eutrophication of coastal waters causes an increased production of algae (phytoplankton and ephemeral and opportunistic macroalgae). The increased density of phytoplankton increases the coastal turbidity of the water causing a reduction of light penetration. The maximum depth of growth of macroalgae as well as submersed phanerogams will be reduced. The increasing production consequently increases the amount of organic material. The bacterial decomposition of this material can cause low oxygen contents or, under certain circumstances, complete oxygen depletion. Therefore, eutrophication will cause long term changes in the species composition (e.g. Mäkinen *et al.* 1984, Kautsky *et al.* 1986, van Vierssen & Prins 1985, Sundbäck *et al.* 1990, Leppäkoski & Mihnea 1996, Bonsdorff *et al.* 1997).

The increasing number of phytoplankton blooms world-wide might be caused by a) increasing eutrophication and b) increasing shipping and amount of ballast water carried around the world (Jones 1991, Bolch & Hallegraeff 1994, Hallegraeff 1995).



Acartia tonsa, a copepod crustacean

15. Need for risk assessment

Increasing utilisation of the coastal zone for aquaculture in the Nordic countries enforced the need to minimise unwanted species introductions. Former studies indicated that every single vessel entering coastal waters has the potential to introduce an unwanted NIS. One introduced species can cause severe harm to the environment and economy (see above). In order to identify the potential of a vessel to introduce unwanted species, the ballast water of these vessels needs to be sampled and analysed. Not all vessels calling for a port in the Nordic region can be sampled. Therefore, a risk assessment is needed to concentrate on target vessels containing ballast water of critical origin.

15.1. Review of risk assessment methods

Several methods have been developed in order to identify and/or quantify the risks of future species introductions and estimate:

- the probability that the introduced species will survive in its new environment

- the probability that the introduced species will establish a self-reproducing population

and

- the probabilities that the introduced species will cause harm (Hayes 1997).

15.1.1. Australian approach

A structured approach to decision making concerning the risk posed by individual vessels is highly desirable for the effective administration of any countries ballast water management regime. Critical factors can be taken into account concerning the potential risk posed by any vessel voyage and as a consequence the action required of an individual vessel on a local specific basis (MEPC40/INF.7, Hayes 1997).

Decision Support System

As a possible way to minimise the risk of introducing NIS with ballast water, Australia has proposed a Decision Support System. This system is designed to evaluate the risk posed by each incoming vessel. The risk assessment component takes into account such criteria as the port of uptake of the ballast water (climate and species composition), the treatment of the ballast water en route, the tolerance of the species which could have been taken on board with ballast water and transported to the area of planned discharge, and the estimated survival rates of the species in the ballast water during the voyage.

The estimation of the survival rate is based on results achieved through sampling a ballast tank before departure as well as immediately after the ballast water uptake, and further during the voyage. Other aspects are the length of the journey and the time of the day of the ballast water uptake. The time of the day is of importance due to the daily migration of species in the water column. Several studies showed that with increasing time in the ballast tank the number of species and specimens decreased dramatically (MEPC40/INF.7, Hayes 1997).

Target species - a Black List

Lists of target species representing high risk species compiled by scientists and authorities are in preparation in several countries. At present Australia's target species, recognised as harmful and unwanted, are: toxic dinoflagellates (e.g. *Gymnodinium catenatum*, *Alexandrium* spp.), North Pacific starfish (*Asterias amurensis*), cholera (*Vibrio cholerae*), Japanese kelp (*Undaria pinnatifida*), giant fan worm (*Sabella spallanzani*), European shore crab (*Carcinus maenas*), and fish pathogens. All of these species are known to be introduced to Australian waters. The list will be modified from time to time as additional information becomes available (Paterson 1996, Lockwood pers. comm.).

The main purpose of the Australian target species list is to minimise the spread of these species within the country by preventing secondary introductions in domestic trade and to minimise future (multiple) introductions of these species by international shipping.

15.1.2. The USA approach

Target species

In the USA the target species list entitled "America's Least Wanted", focuses, as well as the Australian list, on those nonnative species that are introduced and threaten natural environments. Aquatic and terrestrial species are listed: zebra mussel, purple loosestrife, flathead catfish, tamarisk, rosy wolfsnail, leafy spurge, green crab, *Hydrilla*, balsam wooly adelgid, *Miconia*, Chinese tallow and brown tree snake (Nature Conservancy 1998).

Matching climate method

Species are more likely to become established in environments that are similar to those of their origin. Therefore, if the port of loading and port of discharge are ecologically comparable the risk of a species introduction is relatively high.

Probability of colonisation of NIS, according to matching salinity in donor and recipient region, after Carlton (1985)

	DONOR region		
RECIPIENT region	Fresh water	Brackish water	Salt water
Freshwater	high	medium	low
Brackish water	medium	high	high
Salt water	low	high	high

15.1.3. Matching climate and salinity method, Germany

During the German shipping study (1992–1996) all NIS sampled from the ballast water, tank sediments and ship hulls were characterised by an estimated probability of establishment in German waters. All species were sorted into three categories: (1) establishment in German waters improbable, (2) establishment probable, and (3) establishment highly probable. The potential for an establishment was estimated in accordance to the scheme developed by Carlton (1985), taking into account the climate in the area of origin (donor area) and the recipient area where the species could be introduced to.

In addition, a similar scheme was employed to compare the salinity tolerance of the species and the salinity conditions of the receiving waters.

Probability of colonisation of NIS, according to matching climate in donor and recipient area, after Gollasch (1996)

	DONOR region			
RECIPIENT region	Arctic & Antarctic	Cold-temperate	Warm-temperate	Tropics
Arctic & Antarctic	high	medium	low	low
Cold-temperate	medium	high	medium	low
Warm-temperate	low	medium	high	medium
Tropics	low	low	medium	high

If habitats from freshwater and estuarine conditions to fully marine areas are present, the salinity might not be the limiting factor for successful species introductions. The climate might be the most important factor enabling a species introduction. Therefore, all species native to cold-temperate climate areas were quoted in category 3: establishment highly probable. The number of species and specimens decreased with an increasing duration in the ballast tank. Therefore, species native to cold-temperate areas of the northern hemisphere of the Atlantic Ocean (North American east coast and the upwelling area off western Africa) were quoted as high risk species due to the comparable short duration of the ships voyage and matching climates. About 12 % (32 species) of the determined NIS were quoted in this category. Among others, the decapod *Hemigrapsus penicillatus*, native to the cold-temperate areas of Japan, was listed in this category. *H. penicillatus* is believed to be the most recent macrobenthos invader to European waters (first record from the Atlantic coast of France in 1994). The introduction of *H. penicillatus* indicates that the applied model gives a useful first estimation on the probability of establishment.

15.1.4. Résumé of risk assessment methods

Most of the NIS with more or less known dispersal history have been introduced by shipping and most of the important ports of the world are located in estuaries or on the coast. This does not implicate that species will not be transported to freshwater ports by shipping. For example, ballast water transported from St. Petersburg (Russia) to Hamburg (Germany) and vice versa has the potential to introduce freshwater species. Both ports are located in freshwater areas and the duration of the voyage is short. Therefore, a ballast water release at both ends of this shipping route has the potential to introduce NIS.

Exceptions

It has to be taken into account that all general rules or models have their exceptions and can not be applied for all habitats.

Climate and salinity

Matching temperatures in the area of origin and the new habitat do not explain the potential of a species to tolerate or adapt to temperatures uncommon within its native range. A well known example is the ship boring mussel *Teredo navalis* (often called ship worm because of its wormlike habitus), believed to be of tropical origin and was introduced with wooden sailing vessels. Nowadays, the species occurs and causes damage to wooden man-made installations in warm-temperate and even in cold-temperate climates. The first documented record in Europe was a mass occurrence of the species resulting in great damages to tide protection installations, quays and wharves along the coasts of The Netherlands, Germany and Denmark in the 1730s. The species was often found in the western Baltic Sea due to secondary introductions by ships or salt water inflows from the North Sea. Until the early 1990s, no self-reproducing population was observed in the Baltic Sea. Recently larvae of the ship worm were found at the eastern German Baltic coast.

The tropical species *Teredo navalis* was surprisingly able to adapt to cold climates and to lower salinities of brackish waters. None of the established risk assessment models of today would have quoted this species on the list of hot spot species for the introduction into cold-temperate and brackish waters.

Another such example is the establishment of the tropic green alga *Caulerpa taxifolia* in the Mediterranean, where it surprisingly can survive winter temperatures down to 7-10 °C (Wallentinus pers. comm.).

"Ecological niche"/partly empty niche

Another example is the diatom *Odontella* (=*Biddulphia) sinensis*, native to tropical waters, first recorded in Danish waters of the North Sea in 1903. It was assumed that the species was introduced by a ship (Ostenfeld 1908). Many native species (benthic and planktonic species) of the genus *Odontella* occurred in the North Sea both at that time and today. Nevertheless, *O. sinensis* spread rapidly through European waters and established a self-reproducing population. It is believed that the reason for its successful establishment was an empty temporal niche, related to the tendency of the species to bloom as late as in November. But even during blooming periods other native species occur in higher numbers. Long term investigations showed that the population growth of other phytoplankton species was depressed by high populations of *O. sinensis*. Therefore, no empty niche was available, but a partly empty niche. The role of vacant or partly vacant ecological niches, as a relevant factor to manage future invasions, will become clearer when our knowledge on the community structure increases (Williamson 1996).

No empty niche available

NIS can invade areas were no empty niche is available due to more resistance to pollution or due to a higher reproduction rate than native species. The zebra mussel *Dreissena polymorpha* invaded e.g. the most diluted areas of the Baltic Sea and North American Great Lakes. These ecological niche of this species is characterised as a fresh water filter feeder. Both systems have native freshwater filter feeders belonging to the family Unionidae. The native mussels were regionally driven extinct by the introduced zebra mussel. Therefore, the non-availability of an empty niche is not generally an excluding factor for further species introductions.

15.2. Situation in the Nordic countries

It has been indicated in previous studies that the probability of species introductions increases with a wide range of climate and salinity conditions. The Nordic countries cover zones of arctic to cold-temperate climate. Prevailing salinities in the coastal areas range from marine waters (Norway) to freshwater habitats (St. Petersburg), and a wide range of habitats are available (see above). A list of well known species introductions to the Baltic and North Sea, will give an overview on the variety of species and the impacts they have caused. Furthermore, the first approach was undertaken for a list of target species potentially able to become established in the Baltic Sea.

15.2.1. Case histories of introduced species in the Nordic region

15.2.1.1. Phytoplankton and macroalgae

Odontella sinensis (Diatomophyceae) was first reported in the North Sea in 1903. Originally the species belongs to the phytoplankton of the Indo-Pacific region. The species was introduced into Scandinavian water via ships' ballast water and is today a member of the flora of the entire Baltic proper and west coast of Sweden (Ostenfeld 1908, Leppäkoski 1984).

The diatoms *Coscinodiscus wailesii* and *Thalassiosira punctigera* were first reported in Norway in 1979. It is believed that the two species have arrived to Europe with imported oysters (Jansson 1994). *C. wailesii* is today present in The Skagerrak and in the Oslo Fjord, while *T. punctigera* is additionally reported from Kattegat (Kuylenstierna & Karlson 1997).

Alexandrium tamarense and *A. minutum* (Dinophyceae), potential harmful plankton algae (known to cause Paralytic Shellfish Poisoning or PSP), have not been encountered previously, but are today present along the Swedish west coast and in the Oslo Fjord. These species produce cysts or resting spores, which are found in the sediment from the entire county of Bohuslän (Persson/Godhe 1997).

Furthermore, resting stages of potentially harmful phytoplankton species have been found in Nordic waters. *Gymnodinium catenatum* (Dinophyceae) cysts have previously been reported from sediment cores dated to the Middle Age, but were not found in sediment from the 18th century nor in more recent sediment (Dale & Nordberg 1993). In 1993 the cysts were again found in Danish waters (Ellegaard *et al.* 1993) and later in the Kiel Bight, Germany (Nehring 1996) and along the Swedish west coast (Godhe & Persson 1995). *G. catenatum* is a potential PST producer and since then monitoring programmes have been alerted to look for the planktonic stage of *G. catenatum*, however, it has not yet been recorded. *Gyrodinium* cf. *aureolum* (= *G. mikimotloi*) (Dinophyceae) was first observed in the Kattegat in 1981 (Jansson 1994) and is today also recorded in the Skagerrak (Kuylenstierna & Karlson 1997). When *G.* cf. *aureolum* blooms it has caused fish mass mortality in several places due to clogging of the gills (Hallegraeff 1995).

Prorocentrum minimum (Dinophyceae), a species known to cause a different shellfish poison, was first recorded in the Kattegat in 1981 and in the Baltic proper in 1983 (Jansson 1994). Today it is also present in the Skagerrak (Kuylenstierna & Karlson 1997).

***Sargassum muticum* (Japanese seaweed, brown alga)**

The Japanese seaweed was first recorded in Europe in southern U.K. in 1973, but it could have been unintentionally introduced in France as packaging material or as fouling species (most likely) on, or as packaging material for, imported oysters from Japan in the 1970s. These large brown algae are now being found along the coasts of Portugal, Spain (Atlantic coast), France (Atlantic and Mediterranean coasts), United Kingdom, The Netherlands, Germany (North Sea) Denmark (North Sea and Kattegat), Norway and Sweden (west coast). The first findings of drifting *Sargassum muticum* were recorded in 1984 in the Limfjord, in Norway in summer 1984 and a year later in Sweden (Skagerrak). In 1987 the first attached algae were observed on the Swedish west coast and in 1988 in Norway. New localities were reported and today *S. muticum* is established and a permanent member of the algal flora. Sessile plants have been recorded from the Swedish county of Halland to north of Bergen in Norway. Since 1993, when an inventory of the distribution of *S. muticum* was made in Sweden, the alga has expanded southward 100 km. In 1993 it was mainly established in the outer archipelago; 1996 it had expanded toward the coast at many sampling sites. Already in the 1993 the occurrence of *S. muticum* was increasing northward along the coasts, and the trend persisted in 1996. The number of recorded individuals is substantially lower in the Kattegat compared to the numbers in the Skagerrak, with one exception. High numbers of very tall (up to 4 m) and wide plants are found close to the Ringhals nuclear power plant in the middle of Halland, which emphasises the role such areas have for introduced species. The fast expansion of *S. muticum* along the Swedish west coast caused one of the most recent dramatic changes of the sublittoral vegetation belt. Today the distribution of *S. muticum* is known, also how fast it grows, to what extent the growth varies between different years and which organisms are associated with the algae.

Negative effects are competition with the native species, the hindrance of light penetration and water exchange, as well as the hindering of local fisheries. Very dense populations may create problems to run outboard engines of small boats (Karlsson 1988, Wallentinus 1992, Swedish Environmental Protection Agency 1997, Godhe 1998).

In more saline Nordic waters there are also other examples of introduced seaweeds: the red alga *Bonnemaisonia hamifera* from the Pacific Ocean, the green alga *Codium fragile* from the Pacific Ocean introduced into Europe with imported oyster, ballast or fouling, the red alga *Dasya baillouvianna* and the brown alga *Fucus evanescens* from North Atlantic via ships or as drifting plants. *F. evanescen*s is since 1989 also registered in the Belts and since 1991 in the western Baltic (Jansson 1994).

15.2.1.2. Fauna

***Gonionemus vertens* (Hydrozoa, Cnidaria)**

The cnidarian species *G. vertens* was first recorded in Nordic waters in 1921, introduced via ships' ballast water, through fouling or with oysters (Jansson 1994). This species now occur along the entire west coast in the *Zostera* or macroalgal beds were it feeds on amphipods, isopods etc (Hansson 1993).

***Dreissena polymorpha* (zebra mussel) (Bivalvia, Mollusca)**

The zebra mussel *D. polymorpha*, a Ponto-Caspian species was unintentionally introduced into the Great Lakes (USA) in the mid 1980s. Nowadays it occurs in very high densities. This species causes economic problems and is ecologically harmful. Water supplies of power plants and urban water services are densely clogged by this species and have to be cleaned (Roberts 1990, Lodge 1993). The control, repair and actions to remove the introduced zebra mussel in the Great Lakes will cost US$ 500 million until the turn of the century. The mussels displace native bivalves, clog water intakes and foul vessel hulls, fishing nets and other submerged hard material such as port installations, piers and buoys. Long before this mussel invaded many areas of Europe via shipping, or by natural means due to migration via freshwater waterways and canals as well as transports by migrating birds. It was first found in teh Baltic in 1824. In Polish estuaries the zebra mussel may reach high densities, forming up to 88 % of the biomass of benthic fauna (Leppäkoski 1984, 1994, von Bodungen & Zeitschel 1995). Mass occurrences appeared in the 1850s and 1970s in some German rivers and lakes.

Most recently the mussel was recorded from the Shannon estuary (Ireland) (Minchin 1998) and the La Plata river (Argentina).

Its huge filtering capacity makes water clearer and the mussel has also been marketed as a biotechnological tool for areas with heavy algal blooms (Reeders 1990).

***Ensis americanus* (Syn. *E. directus*) (Bivalvia, Mollusca)**

The North American razor clam *E. americanus* was introduced to Europe via ships' ballast water. It was first observed in German waters in 1978 (von Cosel *et al.* 1982) and it is believed to have been established on the Swedish west coast since 1982. In 1986 dead shells with clear traces from four years of growth were first recorded on the beaches of Bohuslän. Today the species is reported as far south as Öresund (Hansson 1993). In Norway the species was first recorded in 1989 and today it is present from Oslofjord to the county of Aust-Agder (Brattegard & Holthe 1997).

Mya arenaria* and *Teredo navalis* (Bivalvia*)

Mya arenaria, the soft shell clam, is a common species often found along the beaches as far north as the Bothnian Sea. It was probably brought to Scandinavia from North America, as early as in the 11th or 12th century, by the Vikings who used the clam as bait or food (Jansson 1994).

Teredo navalis, the shipworm, was brought to Europe from East Asia (Jansson 1994) and is today spread in Scandinavia as far as the Southern Baltic (Hansson 1993).

Crepidula fornicata American slipper limpet (Gastropoda, Mollusca)

C. fornicata, also called oyster pest, has been brought to Europe with imported oysters from North America (Jansson 1994, Minchin *et al.* 1995). This species is today established in the Kattegat and Skagerrak and competes with oysters for food (Hansson 1993). The species is present in Norwegian waters from the Swedish border to the middle and northern part of Rogaland (Brattegard & Holthe 1997).

Potamopyrgus antipodarum (Syn. *P. jenkinsi*) (Gastropoda, Mollusca)

P. antipodarum, a small mud snail from New Zealand, was first observed in Swedish waters in 1887, and was probably brought to Europe via ships' ballast. It occurs frequently all along the Swedish coast as well as in freshwater (Jansson 1994). In Norwegian waters it occurs from the Swedish border to Stavanger (Brattegard & Holthe 1997).

Marenzelleria viridis (polychaet worm) (Polychaeta, Annelida)

M. viridis was first found in the Ems estuary at the border of Germany and the Netherlands in the early 1980s. First records in the Baltic Sea were made in 1985 (Laine 1995) often close to ports, indicating a possible introduction via ballast water (Olenin pers. comm.). Now it occurs in great numbers in the various brackish waters of the southern Baltic Sea (e.g. the Boddens). Its expansion to the eastern parts of the Baltic Sea has continued up to Poland, Lithuania, Sweden and Finland up the southern Bothnian Bay (Stigzelius *et al.* 1997).

It is unknown whether this species has been unintentionally introduced via ballast water or other transport means, or if it has recently invaded the Baltic Sea through range extension. The latter option is less likely because the species does not occur in the inner Kiel Bight and other adjacent areas, where it would be expected to occur first, before spreading further to the eastern parts of the Baltic Sea.

The polychaete inhabits muddy and sandy areas at water depths down to 78 m. In Finnish waters the maximum abundance is shown at depths of 6-40 m (Stigzelius *et al.* 1997). It occurs regionally (Vistula Lagoon) in tremendous densities forming up to 95 % of the total biomass of the zoobenthos (216 g/m^2) (Fall 1993, Zmudzinski 1993, 1996). It has been assumed that even during mass occurrences only limited negative effects, such as competition for food with the native polychaete *Nereis diversicolor* and amphipods, will occur. *N. diversicolor* is a predominately predatory species whereas *Marenzelleria* use dead material (detritus) as a food source (Burckhardt *et al.* 1997).

Adult *Marenzelleria* live in deeper sediment layers than native polychaetes and amphipods. In highly diluted coastal inlets *Marenzelleria* lives deeper than the chironomid larvae and oligochaetes. Therefore, it has been assumed that competition for space plays a less important role (Olenin & Leppäkoski 1999). A beneficial impact for benthic fishes may be the additional food source due to larvae and young adults of *Marenzelleria*. Adults living in deeper sediment layers are well protected and not available for predators (Essink & Kleef, 1986, 1988, Essink 1994, Kube & Powilleit 1997, Bastrop *et al.* 1997, Bochert 1997, Schiedek 1997, Zettler 1997a, b). Its burrowing in deep sediments may enhance denitrification and exchange of materia and energy in the sediment – water interface.

***Balanus improvisus* (barnacle) (Cirripedia, Crustacea)**

B. improvisus established itself in western Europe in the 19th century (Walford & Wicklund 1973), probably introduced by hull fouling of ships from North America. In the German shipping study, *B. improvisus* was one of the most common species in ship hull fouling (Gollasch 1996). It can even survive in fresh water conditions (Kühl 1968). *B. improvisus* now occurs from the Bothnian Bay to the west coast of Sweden, and was first found in the Baltic Sea in 1844 (Leppäkoski 1994). In Norway this species is widely distributed from the Swedish border to the southern part of Nordland (Brattegard & Holthe 1997).

***Elminius modestus* Australian barnacle (Cirripedia, Crustacea)**

The barnacle *E. modestus,* an Australian species, was brought to Europe as the fouling of ships during the World War II. First records were made in England in 1945 (Crisp & Chipperfield 1948). It has replaced *Semibalanus balanoides* in many places in England and is slowly spreading east and northward. Since 1952 it has been found in the Wadden Sea (Kühl 1952). In the Skagerrak it has so far been recorded only on drift wood (Hansson 1993; Jansson 1994).

***Cercopagis pengoi* spiny water flea (Cladoceran, Crustacea)**

The most recent introduction of a nonnative species into the Baltic Sea, is represented by a cladoceran species. In 1992 the invasion of *Cercopagis pengoi* was observed in the Gulf of Riga and in 1995 in the Gulf of Finland. The cladoceran is native to the Caspian Sea and Black Sea region. Its presence causes changes to the food web. It is a carnivorous species preying on native zooplankton species and may thus have a cascading effect on the occurrence of algal blooms. It has appeared to become very abundant during late summer. During mass occurrences fishing nets may be clogged. The beneficial effect is supposed to be the fact that herrings prey upon this species (Ojaveer & Lumberg 1995, Panov pers. comm.). *C. pengoi* was recently recorded for the first time from the North American Great Lakes in 1998 (MacIsaak *et al.* in press).

***Neogobius melanostomus* round goby (Pisces)**

This bottom living fish, native to the Caspian Sea and Black Sea region, was first found in the Baltic Sea (Gulf of Gdansk, Poland) in 1990, introduced as larvae in the ballast water of ships or by active migration via canals and waterways from its native area, (Skora & Stolarski 1993, 1995). The round goby is occupying similar "ecological niches" as other native benthic fish (e.g. flounder, *Platichthys flesus*, black goby, *Gobius niger*, and eelpout, *Zoarces viviparus*) and is therefore expected to compete with these species for food or spawning grounds (HELCOM 1996)

15.3. Target species list of Nordic waters

Prediction of further invasions and problems involved (environmental and economic) is rather difficult (see above), but a discussion on target species is given to get an idea of what the future may hold. Generalisations about the potential of invaders, over a range of wide taxonomic groups (as e.g. crustaceans or molluscs), have too many exceptions to be useful.

Box 14

TARGET SPECIES

This species list compiles harmful aquatic species introduced to areas outside their native range but not in the Baltic Sea by unintentional transports in ballast water or on ship hulls. All species can potentially survive the conditions of the Nordic coastal waters including the outer parts of the Baltic Sea.

Pathogens	**Current area of distribution**
- fish pathogens * - ***	world-wide
- *Vibrio cholerae* (agent of human cholera disease) *	S. America, Asia
Algae	
- *Undaria pinnatifida* (macroalga) ***	France, Mediterranean Sea, U.K. Asia, Australia, New Zealand, Argentina
- *Macrocystis pyrifera* (giant kelp) ***	Pacific, once farmed in France but removed after one summer (13 m long!)
- toxic dinoflagellates or other groups causing harmful	world-wide
algal blooms, especially *Pfiesteria piscicida* **	N. America (ec)
Higher plants	
Zostera japonica (phanerogam) *-**?	Asia, N. America (wc)
Animals	
- *Mnemiopsis leidyi* (comb jelly, ctenophore) ** - ***	N. America (ec), Black Sea, Mediterranean Sea
- *Maeotias inexspectata* (Black Sea jelly fish)**	Black Sea, San Francisco Bay
- *Blackfordia virginica* (cnidarian) **	N. America (ec), Black Sea
- *Haliplanella lineata* (cnidarian)***	Asia
- *Potamocorbula amurensis* (bivalve)**	Asia
- *Asterias amurensis* (starfish) ***	Asia, Australia
- *Hemigrapsus penicillatus* (Asian decapod crab) **	Asia, France, Spain, Atlantic coast
- *Hemigrapsus sanguineus (*Asian decapod crab) **	Japan, N. America (ec),
- *Sabella spallanzani* (giant fan worm, polychaete) ***	Mediterranean Sea, Australia
- *Sphaeroma quoyanum* (boring isopod)***	Australia-New Zealand, San Francisco Bay

- *Balanus eburneus* (barnacle) ***	N. America (ec), North Sea, Black Sea, Caspian Sea, India,Westafrica
- *Rapana thomasiana* (gastropod)** - ***	Japan, Black Sea
- *Cunearca cornea* (bivalve)***	Indo-Pacific, Black Sea, Adriatic Sea
- *Dreissena bugensis* (bivalve)** - ***	Ponto-Caspian, Great Lakes
[- *Ficopomatus enigmaticus* (polychaete)**-***	Indo-Pacific, Black Sea]
[- *Rithropanopeus harrisi* (dwarf crab, decapod)**	N. America (ec), The Netherlands]
[- *Callinectes sapidus* (blue crab, decapod) ** - ***	N. America (ec), Mediterranean Sea, North Sea, Bay of Biscay, Black Sea]
[- *Limulus polyphemus* (horse shoe crab) ** - ***	N. America (ec)]
- Hypania invalida (polychaete) * - **	Ponto-Caspian
Other potential Ponto-Caspian invaders (see text)	

* freshwater species, ** brackish water species, *** marine species, [ ] species found in Nordic waters, see 10.2, ec = east coast, wc = west coast.

A target species is an organism that is potentially able to become introduced and is known to cause large-scale environmental problems due to impacts on native biodiversity and/or economic effects. A list of target species may be used as a first step to evaluate the potential danger to the Nordic sea areas. All listed species (Box 14) are known to have been introduced to and become established in waters outside their native range in temperate climates. Therefore, these species may become introduced to the Skagerrak region and coastal waters of Norway, Denmark and Iceland, and the most euryhaline species may even become introduced into the Baltic Sea.

15.3.1. Harmful algal blooms

Recent concerns about phytoplankton transport in ballast water arose after increasing phytoplankton blooms around the world in the 1980s (Smayda 1990, Hallegraeff & Bolch 1992, Rigby *et al.* 1993). Increasing toxic algal blooms of NIS in (e.g.) Australian and New Zealandian waters have been associated with ballast water releases. In January 1993 the whole New Zealand shellfish industry was closed as a result of toxic algal blooms. Australian scientists have intensified their ballast water studies (Hallegraeff & Bolch 1991, 1992, Baldwin 1992).

In 1992 an IOC-FAO Intergovernmental Panel on Harmful Algal Blooms (IPHAB) had its first session focussing on the negative impacts of these blooms on public health and economy. The expansion of these blooms is related to the increasing exploitation of coastal waters (waste disposal, aquaculture, maritime commerce and other anthropogenic influences) as well as to the dispersal and proliferation of such species.

The IPHAB recognised in its report in 1993 that the problem of the transport of algae, causing harmful blooms via ballast water, was of major concern as already addressed by the IMO and ICES WGITMO earlier. The problem is particularly in regard to toxic marine phytoplankton species such as *Alexandrium minutum*, *A. tamarense*, *Gymnodimium catenatum* and *Gyrodinium* cf. *aureolum* which are known to have occurred in blooms all over the world.

Alexandrium species have caused outbreaks of Paralytic Shellfish Poisoning (PSP) in Norwegian waters and coastal areas of the United Kingdom. Motile *A. minutum* was observed for the first time in 1996 at the Swedish west coast (Skagerrak), when being abundant during the end of June (Lindahl & Edler 1997), while cysts were recorded already in 1995 (Persson/Godhe 1997).

Gyrodinium cf. *aureolum* has caused fish kills in the British Channel, western areas of United Kingdom, and Danish, Norwegian and Swedish waters (Swedish Environmental Protection Agency 1997).

15.3.2. *Pfiesteria piscicida*

The phantom alga *Pfiesteria piscicida* has not yet been found in European waters, but occurs in several estuaries on the North American east coast (e.g. in the Chesapeake Bay). *Pfiesteria* prefers shallow, warm and brackish water. It has a broad salinity tolerance and can occur in freshwater, if the water has high levels of calcium, but the optimum salinity is 15 PSU. *Pfiesteria* can occur in temperatures between 15 to 33ºC, but the optimum temperature is 26ºC (http://www.state.nj.us/drbc/rpfeist.htm). It is believed that this species may be transported and introduced via ballast water or tank sediment. *P. piscicida* and other dinoflagellates have been made responsible for recent estuarine fish kills on the U.S. eastern seaboard and have also been reported to threaten human health.

P. piscicida is known in 24 different forms and is able to produce dormant cysts that may survive for years. Some of these stages are extremely tolerant also to concentrated acids. Some of these stages feed on fish body fluid. The waste from fish swimming above the resting stages of the dinoflagellate, triggers the cysts to change to a toxic life form. These migrate towards the water surface and anaesthetise the fish with their poison and start to feed on the fish fluids from the body tissue. When the fish dies, *Pfiesteria piscicida* starts to reproduce and the next generation of cysts return to the bottom sediments waiting for their prey (Burkholder *et al.* 1993).

A combined set of environmental conditions and clinical signs and symptoms may together represent adverse consequences of exposure to these organisms. The environmental conditions are exposure to estuarine water, characterised by any of the following (Burkholder *et al.* 1993):

1) fish with lesions consistent with *P. piscicida* or morphologically related organisms (MROs) toxicity (20 % of a sample of at least 50 fish of one species having lesions);

2) a fish kill involving fish with lesions consistent with *P. piscicida* or MRO toxicity; or

3) a fish kill involving fish without lesions, if *P. piscicida* or MROs are present and there is no alternative reason for the fish kill.

Thirteen people who worked with dilute toxic cultures of *Pfiesteria piscicida* sustained mild to serious adverse health impacts through water contact or by inhaling toxic aerosols from the cultures. These people generally worked with the toxic cultures for 1-2 hours per day over a 5-6 week period. The effects include a suite of symptoms such as narcosis (a "drugged" effect), confusion, development of acute skin burning (in areas that directly contact water containing toxic cultures of *P. piscicida*, and also on the chest and face), uniform reddening of the eyes, severe headaches, blurred vision, nausea/vomiting, sustained difficulty in breathing (asthma-like effects), kidney and liver dysfunction, acute short-term memory loss, and severe cognitive impairment, headaches, skin rash, upper respiratory irritation, muscle cramps, and gastrointestinal complaints (i.e., nausea, vomiting, diarrhea, and/or abdominal cramps). Most of the acute symptoms proved reversible over time. Some of these effects have recurred (relapsed) in people following strenuous exercise, thus far up to six years after exposure to these toxic fish-killing cultures. Moreover, subcutaneous injection of crude toxin preparations from fish-killing cultures has induced serious learning impairment and memory loss in experimental laboratory rats.

The first known fish kills in adjacent waters to the Atlantic Ocean caused by *Pfiesteria* were documented in 1988 at fish culture sites of North Carolina. Fish kills and fish disease events linked to *Pfiesteria* can extend for 6-8 weeks in North Carolina's estuaries (Pamlico Sound region), thus potentially providing the circumstances for humans in field settings to be hurt due to this dinoflagellate toxin. Since 1991, a billion fish have been killed by *Pfiesteria* in the eastern U.S. waters and lately shellfish have also been found to be affected (Burkholder *et al.* 1993, http://www2.ncsu.edu/unity/lockers/project/aquatic_botany/pfiest.html, http://www.epa.gov/owow/estuaries/pfiesteria/fact.html#13).

15.3.3. *Undaria pinnatifida*

The Japanese kelp *Undaria pinnatifida*, also called Wakame, is a popular ingredient of the Japanese cuisine. It was early introduced in China for cultivation purposes for human consumption and was first recorded in Europe in the French Mediterranean in 1971, probably brought in by Japanese oysters. Furthermore, *U. pinnatifida* is believed to have been introduced to Australia in the 1980s in a similar way as the North Pacific starfish *Asterias amurensis* (see below) and has negatively effected fish stocks in Tasmania. About the same time it arrived to New Zealand. In the early 1990s it did also arrive to Argentina, probably by a Korean fishing vessel. In the mid 1980s *U. pinnatifida* was intentionally introduced to French Brittany and is now cultivated in several areas (Wallentinus pers. comm.). It was first recorded in open waters in 1988, but it is known to have become established at sites in France and in New Zealand before 1988 (Byrne *et al.* 1997). It is likely to continue its spread as its spores are easily dispersed by currents and at this stage an eradication seems impossible. In Australia the kelp has already had a detrimental impact on the abalone industry, as it attaches to rocks that are abalone feeding sites. It also makes it extremely difficult to harvest the abalone. The kelp will have an even greater impact when it reaches oyster and other mussel farms and settles on racks, lines and other culturing material (MEPC33/INF.26).

Physical removal of *U. pinnatifida* from a marine reserve area has been undertaken. The success of this action is not yet known (ICES 1997). In 1991 a proposal reached the European Commission requesting financial support for the introduction of the kelp (*Undaria* spp.) to the French coast of the Channel area for commercial exploitation (Nolan 1994). In mid 1990s it was first recorded from the southern coast of U.K., probably arriving there by pleasure boats. Low temperatures in Nordic waters might have decreased the risk of its arrival.

15.3.4. *Macrocystis pyrifera*

The farming of the Pacific brown algae, *Macrocystis pyrifera* from Chile (Brad *et al.* 1974), was an internationally much disputed pilot scale project carried out on the Brittany coast, France, in the early 1970s. The project was not given permission to be repeated (ICES 1981). The plants, transported from Chile, were brought to a hatchery and the spores gave raise to gametophytes from which young sporophytes were grown and introduced into the sea, after about a month. They were allowed to grow for about seven months to a size of 13 m before being harvested in August. It was claimed that they had not reached maturity, although young, still sterile, sporangia had differentiated (Braud *et al.* 1974). There have been no reports during the 1980s of any accidental introductions resulting from this project. However, it does not exclude the algae from the list of potential introductions, and the size of this species, if established, could have drastic effects on the habitat.

15.3.5. *Zostera japonica*

The seagrass *Zostera japonica* was initially introduced into the USA, probably by imported Japanese oysters in the 1930s or 1940s. It was first reported in 1957 from the state of Washington. After a rapid spread, probably by long distance dispersal of drift plants, the species was commonly found in mid 1970s along the N Washington state shores. It was first reported from S Oregon in mid 1970s (Harrison and Bigley 1982, Posey 1988). The first Canadian record was in 1969 in S British Columbia, after which a rapid spread in the Fraser River area occurred. It reached Vancouver Island in 1979, and in the early 1980s it had colonised the Strait of Georgia. The dispersal in Canadian waters indicates a high potential for surviving in low water temperatures.

15.3.6. *Mnemiopsis leidyi*

The ctenophore *Mnemiopsis leidyi*, endemic to the North American Atlantic coast, is spreading in the Black Sea area. Its first record in the Black Sea was in 1982, and additional findings were reported in 1986. Nowadays the comb jelly is well established, occurs in masses and changes the whole pelagic trophic web. It has played a major role in the catastrophic decrease of the local anchovy industry. The population of native ctenophores has almost been completely destroyed by the invader. Recent mass occurrences of the comb jelly predating on fish larvae and food organisms of fish, local overexploitation and increasing eutrophication problems, resulted in a collapse of the anchovy fishing industry. In the early 1990s the Turkish catch decreased from 295.000 tons in 1988 to 66.000 tons in 1990. The harvest of the anchovies fishery in the Black Sea has decreased by 90 % to the present 10 %, compared with fisheries from the times before the comb jelly invaded the Black Sea (see 5.2.) (Vinogradov *et al.* 1989, Shushkina & Musayeva 1990, Reeve 1993, Leppäkoski & Mihnea 1996, Olenin & Leppäkoski 1997, Zaitsev & Mamaev 1997).

Carefully selected predators such as carnivorous fish (e.g. cod from the Baltic Sea, butterfly fish or chum salmon from North America) or ctenophores predating other ctenophores (e.g. *Beroe* sp. from North America) could be intentionally introduced into the Black Sea for biocontrol purposes. A GESAMP report issued in 1997 reviews control strategies and possible predators for biocontrol, as well as the viability of other, non-biocontrol options (Harbison 1994, Harbison & Volovik 1994, GESAMP report 1997, Gray 1997).

Since the end of the 1980s and early 1990s the population has decreased and the native jelly fish *Aurelia* sp. is increasing again. The continuos depression of the anchovy fishery, even in times of decreasing densities of *Mnemiopsis,* indicates that the invader is not the only cause for the depression (Williamson 1996). Since 1992, the species is regularly found in the Mediterranean Sea (Harbison 1994).

15.3.7. *Asterias amurensis*

The Pacific starfish *Asterias amurensis* was introduced to Australia in the 1970s. In the 1990s the species developed a mass occurrence with hundreds of specimens per 1 m^2 in certain areas and was, therefore, determined as an introduced target species to be eradicated (Hewitt pers. comm.). Established populations of *A. amurensis* have been discovered in cool temperate waters of Southern Tasmania. The starfish is native to Japanese and Alaskan waters and has been known from Tasmanian waters since the late 1980s (first records in 1986), probably introduced by the discharge of ballast water containing the larvae of the species. The impacts of this starfish on e.g. shellfish industries and the marine environment cause concern. It threatens the shellfish industry causing damages of US$ 367.5 million by predation on mussels.

The application of biocontrol methods (e.g. disease agents) is expected to control the population of starfish. There are several problems in biocontrol, especially the need to test the control measures in regard to a selective effect on the target organisms and not on the native species. A possible species for biocontrol could be the Japanese ciliate *Orchitophyra* sp. After infection, this species disables the reproduction of the starfish (Furlani 1996, Thresher and Goggin pers. com., SGBWS 1997).

15.3.8. *Sabella spallanzani*

The giant Mediterranean fan worm *Sabella spallanzani* is threatening aquaculture and fishing industry in Australian waters. This species is characterised by its rapid growth of up to 10 cm per year. The first Australian record was made in the early 1980s. Die-backs of the polychaete were reported from different areas without the knowledge of the causative agent (Furlani 1996).

15.3.9. *Rapana thomasiana*

R. thomasiana was unintentionally introduced into the Black Sea in the 1940s. This benthic carnivorous snail grows up to 16 cm and is a well known predator on mussel beds of oysters and blue mussels. It was assumed that a vessel carrying the eggs in its hull fouling introduced the gastropod. *Rapana* became widespread in the Black Sea, except areas of low salinities. Because of its size, the tourist-mediated ornamental industry started to collect specimens for trade. Since the 1980s snail meat has been delivered for human consumption on the international market. Commercial catches have been concentrated to the Turkish coastal waters. Intensive commercial fishing made the snail population decrease. Its area of origin, the Sea of Japan, and the successful establishment in the Black Sea (Zaitsev & Mamaev 1997) indicate a potential to survive in parts of the Nordic sea area.

15.3.10. *Potamocorbula amurensis*

The Chinese clam *P. amurensis*, being one of the most abundant organisms in San Francisco Bay and occurring also further north in Pudget Sound (Carlton 1996), is a species with a high potential for spreading.

15.3.11. *Hemigrapsus penicillatus* and *H. sanguineus*

The Asian decapod *Hemigrapsus penicillatus* (de Haan, 1835) was first recorded in European waters in 1994. The native habitat of *H. penicillatus* ranges from northern Japan (cold-temperate climate) to China (warm-temperate climate) (Noël *et al.* 1997, Türkay 1996 pers. com).

The first specimens were collected in the estuary of Charente Maritime at the west coast of France close to La Rochelle. The current range in Europe covers Spanish shallow water habitats of the Bay of Biscay to areas north of La Rochelle (France). Densities of up to 20 specimens/m^2 occur (Noël 1997, Noël *et al.* 1997). This species has a wide temperature (from 0 °C to tropical temperature) and salinity tolerance. Both hard and soft bottom habitats have been colonised. A Japanese investigation showed that *H. penicillatus* was frequently found even in beverage cans (Ogura & Kishi 1985).

Matching climates and salinity conditions will enable the further distribution of the crab in Nordic waters. The high salinity tolerance of the species indicates the Baltic Sea as an especially suitable habitat. It is not clear whether this crab became introduced with shipping by ballast water or as a fouling organism. A study of ship hull fouling in German dry docks provides evidence that hull fouling is a likely vector for the introduction of this crab. In August 1993 six juvenile specimens of *H. penicillatus* were sampled from the hull of a car-carrier (Gollasch 1996, Gollasch in press.).

On the Atlantic coast of North America the Japanese shore crab *Hemigrapsus sanguineus* has spread as far north as Cape Cod (Carlton 1995) and in some regions replaced the previously introduced *Carcinus maenas*.

15.3.12. *Haliplanella lineata* (syn. *H. luciae*)

H. lineata is known as a striking example of a migratory species. It established self-reproducing populations in various regions along the Atlantic coasts of North America and Europe. The origin is supposed to be the western Pacific region. This temperature tolerant species requires a minimum salinity of 12 ppt. It was documented in the intertidal zone of the German Wadden Sea port Büsum in the early 1920s (Stephenson 1935). *H. lineata* was never discovered in the Wadden Sea again. It was supposed that the occurrence of another introduced sea anemone *Diadumene cincta* explains the poor settling of *H. lineata*. *D. cincta* occurs in similar habitats but exhibits effective aggressive behaviour towards other sea anemones (Williams 1975). *H. lineata* seems to be unable to compete successfully today, but the situation might change in the future (Gollasch & Riemann-Zürneck 1996).

15.3.13. Cholera

A cholera epidemic (disease agent: *Vibrio cholerae*) commenced in Eastern Celebes (Indonesia) in 1961 and finally completed its encirclement of the globe in 1991. In South America the epidemic wave started on the coasts of Peru and was documented later from several ports of Latin America. Therefore, it is believed that the Cholera had been introduced by maritime traffic (Epstein 1993). The introduction caused a serious threat to thousands of people's health after consumption of seafood caught in affected areas (Murphree & Tamplin 1992).

In November 1991 and June 1992 the USA documented the detection of active Cholera bacteria in ballast water of vessels coming from South America (McCarthy & Khambathy 1994).

Australia introduced a testing programme for Cholera in 1992 of all vessels from South America and other ports known for Cholera outbreaks. A number of positive tests for Cholera were documented. Six vessels that had taken ballast on board in ports of the Persian Gulf, Singapore and Indochina provided presumptive readings, indicating possible Cholera. On serological testing all were subsequently proven to be negative. Since that time studies are being carried out in order to evaluate the risk of Cholera introductions to Australia via ballast water (Hewitt pers. comm.).

15.3.14. Potential Ponto-Caspian invaders

Ricciardi & Rasmussen (1998) identified 17 Ponto-Caspian euryhaline animal species that have recent invasion histories in the east european rivers and water reservoirs and are likely to be transported in ballast water. Several of these are classified as high-risk species: the fresh water polychaete *Hypania invalida*, the amphipods *Corophium sowinskyi*, *C. curvispinum*, *Dikerogammarus haemobaphes*, *D. villosus*, *Pontogammarus obesus*, *P. robustoides* and *Obesogammarus crassus*, the mysid shrimps *Limnomysis benedeni*, *Paramysis intermedia*, *P. lacustris*, *P. ullskyi* and *Hemimysis anomala*, the cardiid clam *Hypanus* (*Monodacna*) *colorata*, and the fishes *Clupeonella caspia* (Caspian herring), *Benthophilus stellatus* and *Neogobius fluviatilis*. Of these species, *C. curvispinum*, *P. robustoides*, *O. crassus*, *L. benedeni* and *P. lacustris*, have been found in some of the coastal lagoons in the SE Baltic area; *H. anomala* established flourishing populations along the south coast of Finland in the early 1990s (Olenin & Leppäkoski 1999).

15.4. Secondary introductions

After an introduction in one country, secondary dispersal (introductions within the country or into waters of neighbouring countries) can take place, either by natural means (currents, birds, fish) or by recreational and commercial coastal ship traffic or with the transfer of aquaculture species (Jansson 1994, Swedish Environmental Protection Agency 1997). Secondary introduction within Europe should be taken into account, of which the dispersal of the Japanese seaweed *Sargassum muticum* is a striking example. Another example, *Hemigrapsus penicillatus* may be introduced into the Nordic waters by either ships from the native range (Asia) or spread from France where it was first found in 1994 (Noel 1997, Gollasch in press).

15.5. The Nordic countries as donor area of nonindigenous species

The potential export of NIS from the Nordic seas is of equal importance as the introduction of organisms into Nordic waters. The survival potential of "exported" organisms will depend, among other factors, on the physical characteristics of donor and recipient habitats, the area of origin and the duration of transit.

Overseas port areas may be at risk from the introduction of some European species. Most of the important harbours in the world are located at river mouths or in estuaries. The salinity of these brackish habitats (salinity ranges from nearly marine to fresh water) are comparable to the Baltic Sea. Therefore, organisms from the Nordic coasts may establish in ports all over the world with temperate climate and matching hydroclimate. In this way the Baltic Sea, as well as the Nordic harbours along the North Sea and the North Atlantic coasts, serve as donor areas introducing European species into habitats outside their native range.

Two mechanisms of species export from the Nordic waters are obvious. Firstly, species native to the north eastern Atlantic and/or Baltic coasts may be transported and become established in areas outside their native ranges (see list below). Secondly, species previously introduced into the Nordic region may be transported to regions outside the Nordic coasts. Genetic studies may reveal the origin of introduced species more clearly; in some cases an introduced species has been introduced to a new habitat not only from its native distribution area but also from areas were it was introduced in former times. As an example, the area of origin of the zebra mussel population, introduced to the North American Great Lakes is unknown. It might have been transported from its native range or from other places, where it was introduced in the past (Baltic Sea, north western Europe). Other examples are the Ponto-Caspian *Cordylophora caspia* and the Chinese mitten crab *Eriocheir sinensis.* The origin of the introduction of *Codium fragile* ssp. *tomentosoides* to the North American east coast, was probably due to an accidental introduction by ships. It was first recorded in Long Island Sound in 1957, and then rapidly spread along the east coast (see Carlton & Scanlon 1985 for a review) to finally reach Canadian waters in 1990s.

Phytoplankton

Several harmful algae are recorded from the west coast of Sweden that could be liable to be exported to new areas via ships' ballast water. As mentioned above, the resistant resting spores survive very well in the ships' ballast water tanks. The cyst forming and potentially PST producing species, *Alexandrium minutum, A. tamarense* and *Gymnodinium catenatum,* are all found in the sediment of the Stenungsund area (Persson/Godhe 1997). These cysts might be taken into the ballast water tanks while ballasting in the shallow ports and transported to new areas. Other harmful algae that could be exported from the area are *Prorocentrum lima*, a benthic, DST producing dinoflagellate. It lives as an epiphyte on macroalgae, therefore, fouling macroalgae of ships' hull could serve as a vector for the spread of *P. lima*. *Gyrodinium* cf. *aureolum* is a known fish killer that is well present along the Swedish west coast and might become established elsewhere via ships' traffic. Species of the potential AST producing genera *Pseudonitzschia* could also spread further from the Swedish west coast. Several of the harmful microalgae present on the Swedish west coast are not recorded from the Baltic. Some species are true marine species and could not survive in the brackish water of the Baltic, whereas others might survive and become established. The traffic from the ports in the Skagerrak and Kattegat area to ports in the Baltic are extensive and there are several opportunities for microalgae to be transported into new areas.

In the San Francisco Bay 17 out of the 212 NIS aquatic species are of European origin; among them are:

***Littorina saxatilis* (Mollusca, Gastropoda)**

The common North Atlantic snail, *L. saxatilis,* was first recorded in the San Francisco Bay in 1993 and became locally abundant. Further spread of the snail is not excluded (Cohen & Carlton 1995).

***Carcinus maenas* (Decapoda, Brachiura)**

The arrival and establishment in 1989-90 of the European shore (green) crab *Carcinus maenas* in San Francisco Bay signals a new level of a new mode of trophic interference with native food webs. The green crab is a food and habitat generalist, capable of preying on an extraordinarily wide variety of animals and plants, and capable of inhabiting marshes, rocky substrates, and fouling communities. European, South African, and recent Californian studies indicate a broad and striking potential for this crab to significantly alter the distribution, density, and abundance of prey species, and thus to profoundly alter the community structure in the San Francisco Bay (Cohen & Carlton 1995). This species has also been introduced to the North American east coast around 200 years ago, to Australia in the late 19^{th} century and to South Africa in 1983.

***Botryllus schlosseri* (Tunicata)**

This species was probably introduced by hull fouling of ships. It is native to waters of the north east Atlantic Ocean (Cohen & Carlton 1995).

***Ascidiella aspersa* (Tunicata)**

A. aspersa is a common sea squirt on the Swedish west coast. It has been a successful invader of the North American east coast where it has spread from Massachusetts to Connecticut since it was introduced in the mid 1980's. The vectors for spreading *A. asper*sa from Europe to America were either larvae being transported in ships' ballast water tanks or adults fouling ships' hull (Carlton 1993).

In the North American Great Lakes approx. 55 % of 139 NIS established are native to Eurasia, including the Eurasian watermilfoil (*Myriophyllum spicatum*), faucet snail (*Bithynia tentaculata*), common carp (*Cyprinus carpio*) and rudd (*Scardinius erythrophthalmus*). More recent introductions are *Bythotrephes cederstroemi* (a spiny water flea), zebra mussel (*Dreissena polymorpha*), ruffe (*Acerina cernua*), and round goby (*Neogobius melanostomus*), some of which have appeared to be highly aggressive invaders causing a heavy impact on the ecology of the lakes (Mills *et al.* 1993).

16. Summary of actions to reduce the risk

16.1. Intentional introductions (The ICES Code of Practice)

The International Council for the Exploration of the Sea (ICES) was founded in 1902. Within its 19 member countries, ICES has the task to encourage member countries to conduct investigations and research in the sea and co-ordinate research interests, especially in regard to living resources.

The Working Group on Introductions and Transfers of Marine Organisms, developed the ICES Code of Practice dealing with e.g. quarantine measures to prevent the introduction of non-target organisms. ICES adopted the Code of Practice in October 1973 in order to reduce the risks of adverse effects arising from the introduction of nonindigenous marine species for aquaculture purposes. This code has been modified several times and has been translated into most of the ICES member languages.

Box 15

WHAT can be done to reduce risks of new introductions?

Intentional and "hitch hiking" unintentional introductions (aquaculture)

- follow the quarantine procedures of the ICES and EIFAC Code of Practice for planned introductions (aquaculture, research)
- use of sterile specimens for aquaculture to prevent uncontrolled reproduction and genetic impacts
- use of species with low competitive ability

Unintentional introductions (ballast water)

- invest in research on effective, practicable and environmentally sound ballast water treatment methods
- implement the IMO guidelines to exchange the ballast water in open seas, wherever possible
- invest in research activities concerning the hull fouling by developing effective, practicable and environmentally sound antifouling methods

16.2. Unintentional introductions (IMO Assembly Resolution A. 868(20))

At the moment the ballast water management strategies, as e.g. the ballast water exchange in open sea, is largely voluntary. Most of the countries in the world did not even implement these voluntary guidelines.

The International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC) has had a specific interest in the field of unwanted introduced species by ballast water. This was demonstrated in 1973 when the International Conference on Marine Pollution adopted resolution 18, drawing attention to the transport of aquatic organisms and pathogens around the world in ships' ballast tanks.

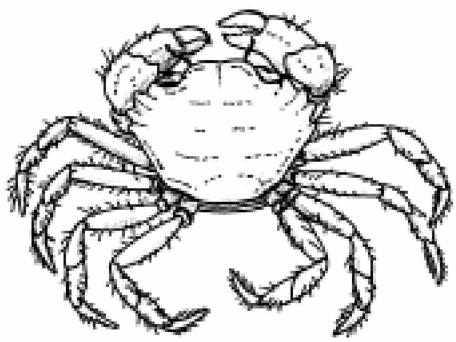
Australia was the first country to bring the ballast water problem into focus and has played a key part in proposing the development of the control mechanisms for the introduction of the ballast water in the early 1990s. In late 1990, the MEPC of IMO formed a working group to consider research information and solutions proposed by Member States of the IMO and by non-governmental organisations.

The working group concluded that voluntary guidelines were the appropriate first step in addressing this problem. MEPC adopted guidelines by resolution in 1991 and in 1993, and these were adopted by the IMO Assembly under resolution A.774 (18) entitled "International Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships Ballast Water and Sediment Discharges". In 1997 the IMO Assembly adopted Resolution A.868 (20) "Guidelines for the Control and Management of Ship's Ballast Water to Minimise the Transfer of Harmful Aquatic Organisms and Pathogens".

This IMO Assembly Resolution is an extremely important step towards the development of provisions in addressing this global problem. IMO has put forward these guidelines to limit the movement of organisms by ballast water world-wide. These include informing ships on areas where ballast water uptake should be avoided due to the presence of harmful algal blooms and known unwanted contaminants, precautionary procedures when taking on ballast water in shallow areas, ballasting with freshwater, discharging ballast water and sediments to on-shore facilities (if available) and the exchange of ballast water at sea.

The IMO Assembly Resolution A.868 (20) recommends an exchange of ballast water in open oceans as far away as possible from the coast. This procedure is currently believed to be the most reliable method in order to minimise the risk of transfer of unwanted organisms. Compared with coastal waters, deep ocean waters contain less organisms and species occurring in open ocean waters are very often not able to survive in coastal zones and vice versa. Where open-ocean exchange is not possible, requirements developed within regional agreements may be applicable, particularly in areas within 200 nautical miles from the coast. It was recommended to avoid ballasting e.g. at night (bottom living organisms may migrate towards the water surface being more likely to be taken in), in shallow areas where the number of organisms is higher and during algal blooms.

If safety permits, all of the ballast water should be released until suction is lost. Stripping pumps or eductors should be used if possible. The flow through method in the open ocean should be employed by pumping ballast water into the tank or hold and allowing the water to overflow, and the tank volume should be pumped through the tank at least three times.



Carcinus maenas, the shore (or green) crab

17. Risk assessment for selected harbour areas

Based on **shipping traffic statistics** (release of ballast water, shipping routes to or from areas of matching climate, salinity etc.), **habitat characteristics** (estuaries, salinity, eutrophication, pollution etc.), **community structure** (number of native species and NIS) and the **potential for secondary introductions,** a tentative risk assessment for the introduction of organism by ships was undertaken.

Selected ports/port regions of Nordic countries were studied focussing on the probability to receive further introductions. Furthermore, the survival probability of nonnative species was considered. For future probability modelling these factors will later be combined. This tentative assessment is meant to provide a base for later conclusions of risk assessment analysis (Box 16).

The port profiles cover a wide variety of habitats in the Nordic countries. The Nordhordaland area represents Northeast Atlantic fjord landscape. The Stenungsund region is located on the Skagerrak coast and represents the transition zone between the North Sea and Baltic Sea with fully marine and brackish environments. The port profile of Klaipeda represents open sandy coasts with lagoons in the south-eastern Baltic. Turku is a predominantly rocky shore region located in the Finnish Archipelago Sea. St. Petersburg is a freshwater port located at the mouth of the large and commercially important Neva river connected to the Russian inland waterways. Those waterways connect the Baltic Sea with the Black and the Caspian Sea (see port profiles 22-26).

The most important factors controlling invasions are temperature and salinity. If both parameters match the area of origin and the recipient region, the probability of an introduction is quite high. The temperature variation of all listed ports plays a secondary role compared to the changing salinity. In the freshwater habitats of St. Petersburg (Russia), it is unlikely that a marine species would become a successful invader, neither in the marine Nordhordaland (Norway) region would any freshwater organism be successfully introduced. The risk assessment takes into account the different salinity regimes in the studied ports and consists therefore of three sections (risk assessment of species introductions in marine, brackish and freshwater habitats) and a summary of risk assessment of species introductions comparing the port profiles.

Box 16

Risk Assessment

- this first, initial risk assessment does not represent an overall perspective, but focuses on potential future NIS introductions by ships and documents a tentative estimation of the risk for further species introductions. Due to the limited data available this risk assessment is still far from prediction
- this risk assessment was undertaken for future introductions of nonindigenous marine and/or brackish species due to the fact that most of the important ports in the world are located in marine or brackish habitats
- studies have shown that more than 90 % of the transported ballast water originate from marine areas (Carlton *et al.* 1995, Gollasch 1996) emphasising the need to study the potential of future introductions of marine and/or brackish species
- changing shipping routes and other regional aspects, such as the political situation, need to be taken into account for further studies on risk assessment. These changes could promote the introduction of species from certain areas by e.g. shifting of traffic routes and/or shipments of goods
- taking into account other introducing vectors (migration of species via canals and waterways), freshwater ports (e.g. St. Petersburg) will probably be considered as high risk areas due to the influences from major canals in the area
- intentional introductions for restocking purposes of invertebrates in adjacent fresh water reservoirs, would probably bring the port of Klaipeda into focus
- one should consider that studies have shown that each single vessel is able to introduce a potentially harmful species. However, knowing the risks, a minimisation of this unwanted input of ships ballast water could be achieved

17.1. Quantification of risk factor level for unintentional future species introductions of marine species by ships.

The quantification of the risk factors from low to high is described in Tab. 1. This table does not cover all known vectors for the introduction of NIS, but focuses on ships (and aquaculture sites).

Table 1. Preliminary risk assessment quotations of future introductions of species (modified from Gollasch in prep.). The figures below are based on the listed categories, low, medium and high as derived from the attached port profiles, but not necessarily limited to the area covered by these profiles.

Risk factor	**Low** **1***	 **2***	**Medium** **3***	 **4***	**High** **5***
Shipping					
Volume of released ballast water					
[in million tons]	<1	<10	<25	<50	>50
Number of ship arrivals in the area					
[number of ships]	<100	<1.000	<5.000	<10.000	>10.000
Major shipping routes to areas of matching climate (per region)					
[%]	<20	<40	<60	<80	>80
Major shipping route to areas of matching salinities (per region)					
[%]	<20	<40	<60	<80	>80
Duration of ship voyages					
[days ballast water lasted in tanks before released, in average]	>100	<100	<50	<10	<5
Habitat					
Number of estuaries in port areas per region					
[number]	0	<2	<4	<6	>6
Salinity gradient within port area					
[salinity range in ppt]	0	<5	<10	<15	>20
Number of aquaculture and fish processing sites					
[number of sites in the area]	0	<2	<10	<25	>25
Number of ship yards					
[number of sites in the area]	0	<2	<4	<8	>16
Degree of water pollution					
[eutrophication, chemical, urban waste, power plants]	Low		medium		High
Community					

Number of macrozoobenthos species per region					
[species]	>1000	<1000	<500	<250	<50
Number of previously known invasions per region					
[species]	<5	<10	<50	<100	>100
Secondary introductions					
Number of nonnative species in nearby areas					
[number of established and non-established NIS]	<5	<25	<50	<100	>100

The risk factors considered in this table are based on estimations on factors controlling the unintentional introduction of aquatic species (Box 6 & 12) (Elton 1958, Wilson 1965, Briggs 1966, 1974, Magnuson 1976, Arthington & Mitchell 1986, Crawley 1986, 1989, Nichols & Pamatmat 1988, Williamson 1989, Leppäkoski 1991, Vermeij 1991, 1996, Carlton *et al.* 1995, Gollasch 1996, Ruiz *et al.* 1997, Cohen & Carlton 1998).

17.1.1. Shipping

Several shipping studies (Hallegraeff & Bolch 1991, 1992, Carlton 1985, Gollasch 1996) showed that the volume of introduced ballast water is an indication on the probability of future species introductions. Furthermore, increasing duration of voyages negatively effects the survival rate of species and specimens in the ballast water. It is important to note that one single ship is in the position to introduce a NIS, but that multiple introductions, due to high number of ships arrivals, increase the risk of successful introductions. A surplus on ships calling for an area in ballast (with limited amounts of cargo on board or not carrying any cargo) increases the risk of species introductions due to the comparably higher amounts of discharged ballast water (Gollasch 1996).

Hot spot areas for future species introductions (Box 12) are characterised by (e.g.) matching climates and therefore the climate of major shipping routes was taken into consideration in this risk assessment.

17.1.2. Habitat

Salinity

Besides the climate, the salinity is an important factor regulating species introductions. Nordic countries represent habitats ranging from fully oceanic coasts of Norway and Iceland to freshwater habitats of the innermost Baltic Sea. It is assumed that port areas with shipping routes operating to ports of matching salinities are more open to species introductions. The port profiles indicate that the last port of call, of most of the ships calling for Nordic waters, is located in brackish or marine waters.

Pollution

In former studies it has been documented that areas characterised by high pollution (eutrophication, chemicals, urban waste waters and influence of power plants) are more open for species introductions (Box 12) (Nichols & Pamatmat 1988, Leppäkoski 1991).

Shipyards

Regions with intensive ship building industries receive higher amounts of NIS due to ballast water and tank sediment discharges during repair and/or inspection work, and by cleaning of the ballast tank sediments and hull fouling of ships.

17.1.3. Community

Communities with low numbers of species are more open to introductions (Elton 1958, Wilson 1965, Briggs 1966, 1974, Magnuson 1976, Vermeij 1991, 1996). About 90 NIS have been recorded from the comparably species-poor Baltic Sea (Olenin & Leppäkoski 1999). In species-rich communities, e.g. the Australian barrier reef, no introduction of a nonnative species has happened (Taylor pers. comm.).

Wilson (1965) and Briggs (1966) documented the multiple introductions of NIS between North America and Europe. The comparable number of species and stability of both regions enables a rich exchange of species (Lindroth 1957, Cohen *et al.* 1995). The number of unintentional introductions between North America and Europe is higher than the amount of intentionally introduced species (Lindroth 1957).

Furthermore, the number of previously introduced species may indicate the availability of this habitat for future species introductions (Wilson 1965, Briggs 1966, Carlton *et al.* 1995, Gollasch 1996).

17.1.4. Secondary introductions

Secondary introductions within the Nordic countries are important vectors for the distribution/range extension of NIS. Therefore, the number of nonnative species in neighbouring areas has been listed as a risk factor.

17.1.5 Risk level quantification

The cumulative risk factor analysis could theoretically reach a value of 65 according to the 13 risk factors listed in Tab. 1 (see above), if the area investigated would always be sorted in the highest risk level category.

Table 2. Quantification of risk factor level for unintentional future species introductions by ships (according to Gollasch in prep.)

Level of risk factor	Risk for species introductions
<10	low
11-25	low-medium
26-35	medium
36-40	high
>40	extremely-high

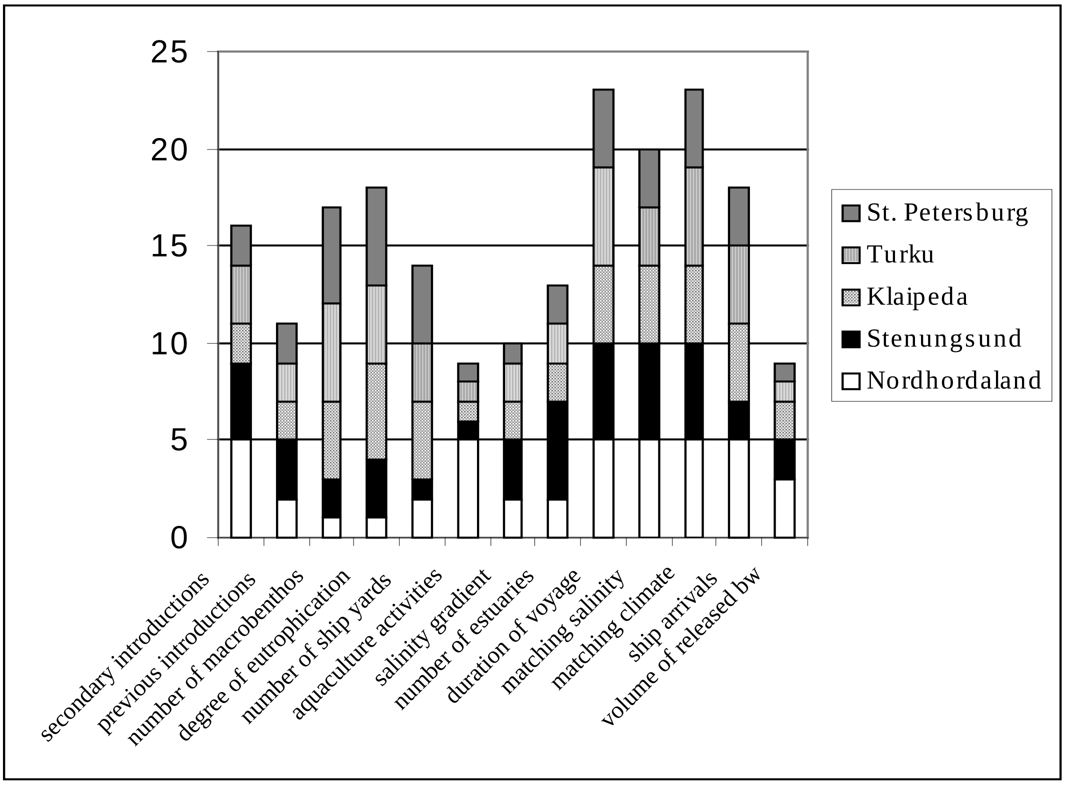
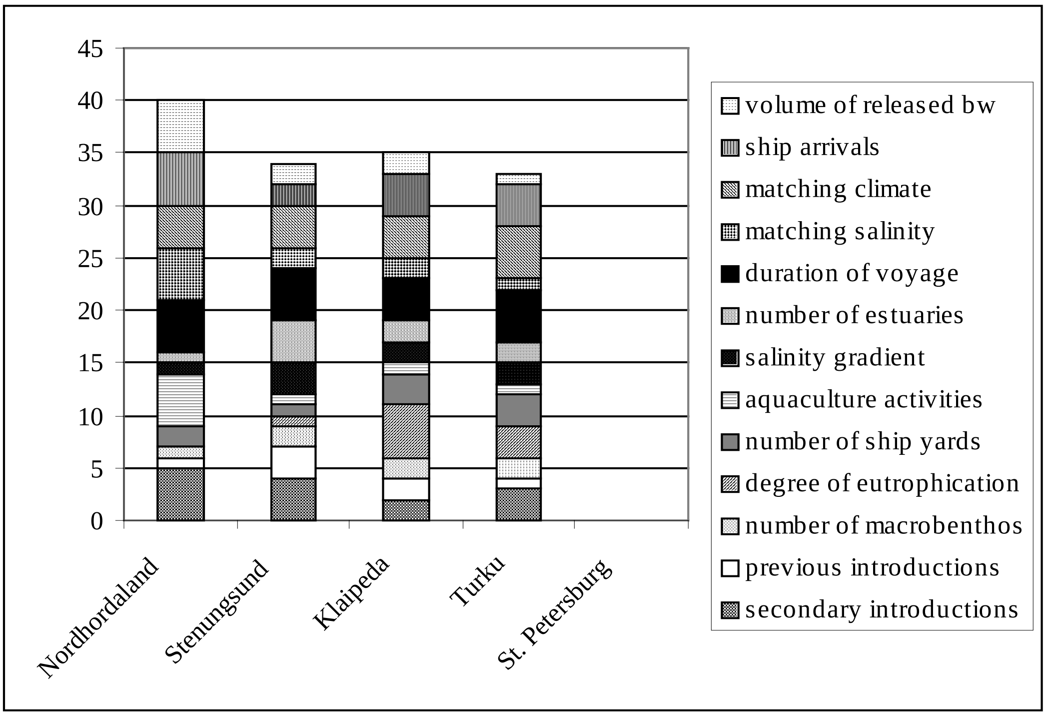


Figure 1. Risk factors of all port regions investigated.

The main vectors of species introductions according to Tab. 1 have been compared for all investigated ports. The most important vectors are duration of voyage and matching climate and salinity (Fig. 1). Apart from this general statement, the specificity of the port regions was taken into account. For example a) the comparably higher amount of discharged ballast water in the Norwegian Nordhordaland region from areas of matching climate and salinity indicates a higher probability of species introductions by ships, and b) the high amount of aquaculture activities in the Nordhordaland region indicates a higher risk of unintentional future species introductions compared to the lower activities regarding aquaculture in all other port regions.

Knowing that the salinity is one of the most important factors controlling future species introductions the risk assessment was undertaken according to the different salinity regimes of the studied port regions. The port profiles were divided into marine (Nordhordaland), brackish (Stenungsund, Klaipeda & Turku) and freshwater (St. Petersburg) habitats.



17.2. Risk assessment for the introduction of marine species

Figure 2. Risk assessment of species introductions by ships to Nordic marine habitats.

* Data of St. Petersburg were not considered knowing that marine species will **not** survive in freshwater conditions.

The highest risk for introductions of marine species, and at the same time the region with the highest risk of species introductions overall is given for the region of Nordhordaland. This is due to the high number of ship arrivals from areas of matching climates and salinities combined with a high potential of secondary marine introductions from the North Sea. Multiple introductions increase the probability of future species introductions. All brackish water regions (Stenungsund, Klaipeda and Turku), are characterised by medium risk. Compared to Nordhordaland, the high number of estuaries in these regions, offer a wide variety of habitats. Many species occurring in marine waters are able to tolerate brackish water conditions at least during some time in their life. Turku, characterised by waters with the lowest salinity, is of comparable lower risk for the introduction of marine species than brackish port regions with higher salinities (Fig. 2). Some of the most important risk factors seem to be the number of ship arrivals, the matching salinity of the area of origin and of the ballast water discharge region, and the high potential of secondary species introductions from neighbouring areas (Fig. 3).

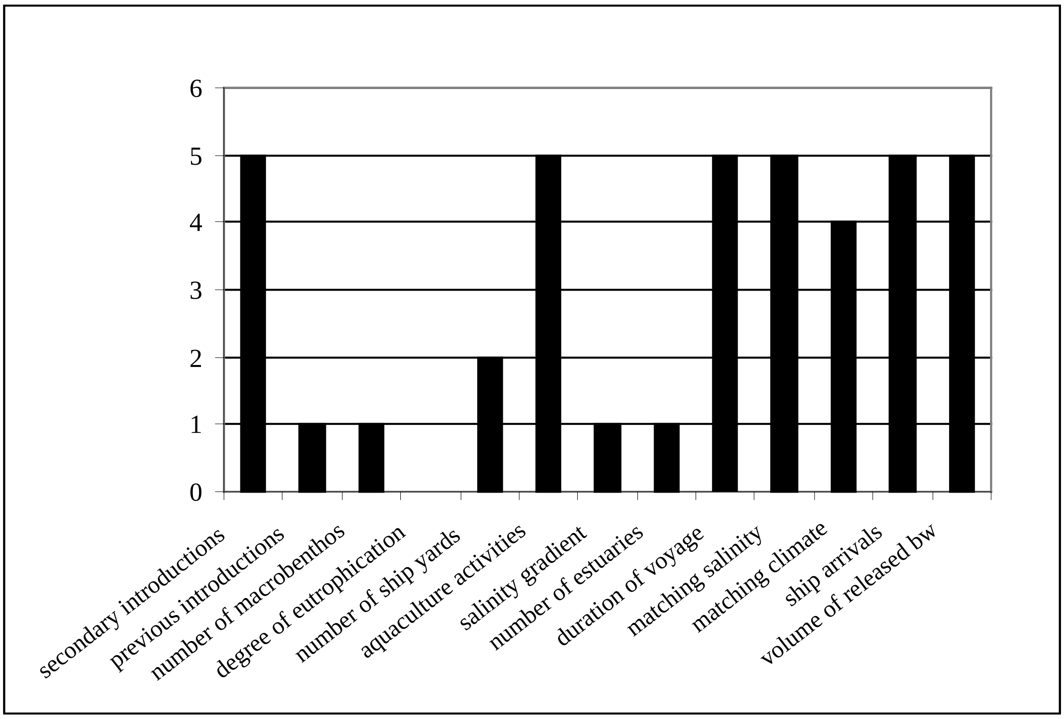


Figure 3. Risk factors estimating the risk of the Nordhordaland area, characterised by marine waters.

17.3. Risk assessment for the introduction of brackish water species

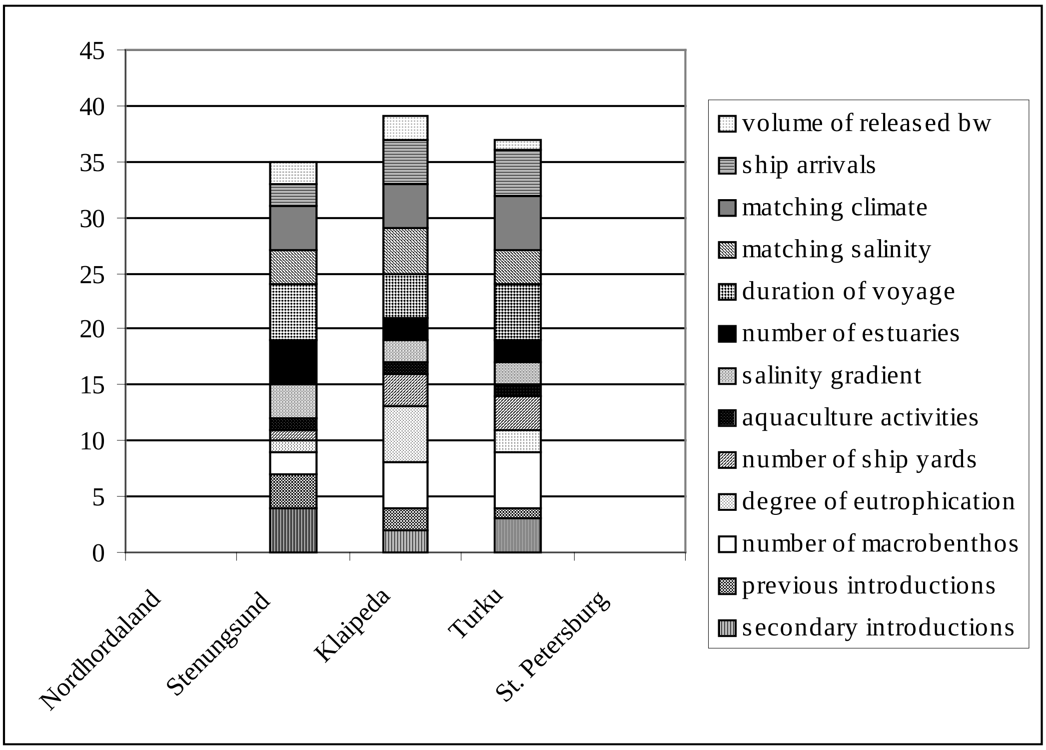


Figure 4. Risk assessment of species introductions by ships to Nordic brackish habitats.

*Data of Nordhordaland were not considered knowing that brackish water species are **unlikely** to survive in marine conditions

Data of St. Petersburg were not considered knowing that brackish water species are **unlikely to survive in fresh water conditions

All three brackish water areas studied are of comparably high risk for future introductions of brackish water species. The port regions of Nordhordaland and St. Petersburg have not been considered knowing that brackish water species are unlikely to survive and establish self-sustaining populations in marine and fresh water habitats. It was determined that all brackish water ports have the high number of ship arrivals, from areas of matching climate and salinity, in common. The comparably short duration of voyages may support the survival rate of species in the ballast water tank and in this way increase the probability of species introductions. The Klaipeda region was quoted to be of highest risk of all brackish areas for the introductions of a brackish water species with ships (Fig. 4). The overall risk level is lower compared to the potential marine introductions in Nordhordaland due to the lower amount of ballast water from brackish regions discharged in the Klaipeda region (Fig. 2). The most important risk factors are the matching salinity and climate of area of origin of the ballast water and discharge, duration of voyages and number of ship arrivals. The amount of discharged ballast water is lower compared to Nordhordaland, but the higher number of ship arrivals increase the risk due to a higher potential of multiple introductions over the year (Fig. 5).

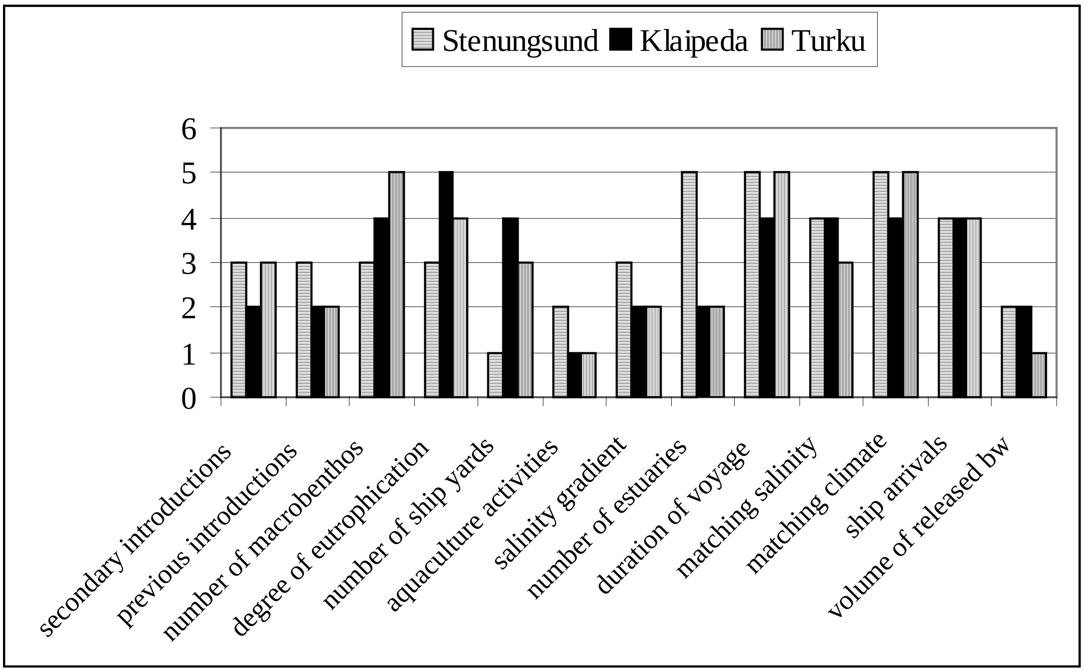


Figure 5. Risk factors estimating the risk of the brackish water ports Stenungsund, Klaipeda and Turku.

17.4. Risk assessment for the introduction of freshwater species

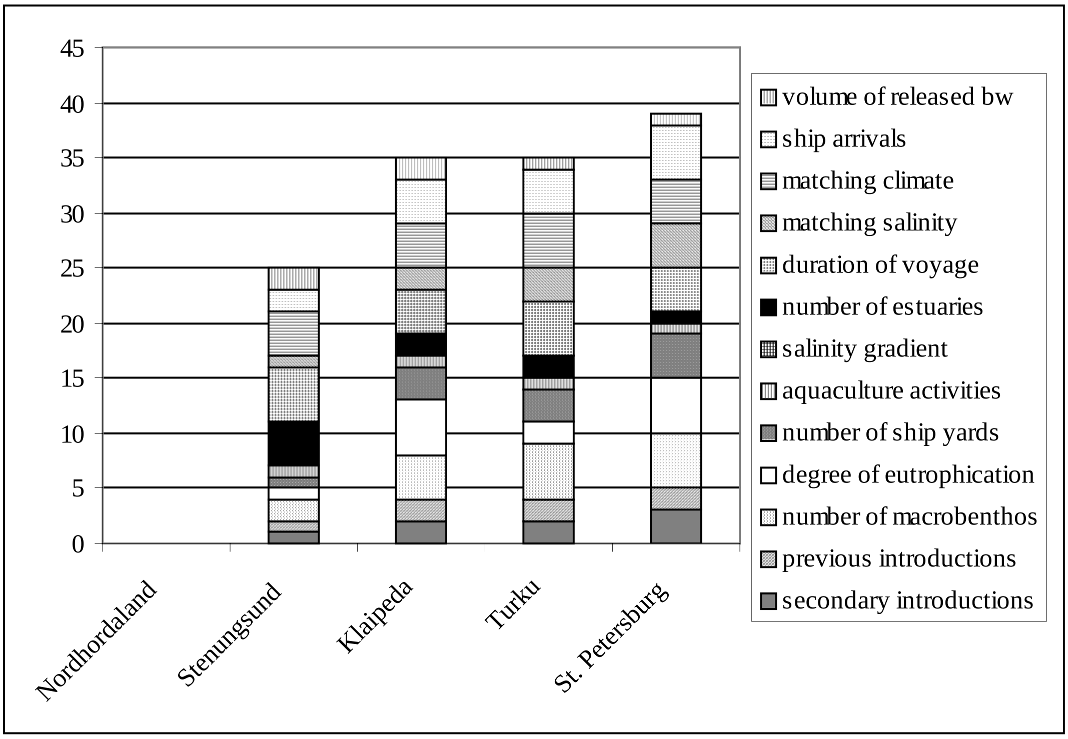


Figure 6. Risk Assessment of species introduced by ships to Nordic freshwater habitats.

* Data of Nordhordaland were not considered knowing that freshwater species will **not** survive in marine conditions.

The high number of ship arrivals from areas of matching salinities combined with a comparably high amount of anthropogenic influence (pollution, power plants and eutrophication) characterises the high risk of the St. Petersburg region for species introductions by ships. Overall shipping statistics and ballast water studies (Carlton *et al.* 1995, Gollasch 1996) revealed that ballast water with freshwater origin was rarely found. More than 90 % of the samples were of brackish or marine origin. This fact alone would rank St. Petersburg as a low risk area for introductions of species with ballast water. However, the location of the St. Petersburg is unique, as ships arrive frequently with ballast water of matching salinities from inland waterways. Consequently, St. Petersburg was quoted as the second high risk area of all compared regions. Stenungsund, with its higher salinities was estimated to be a low risk area of freshwater species introductions by ships.

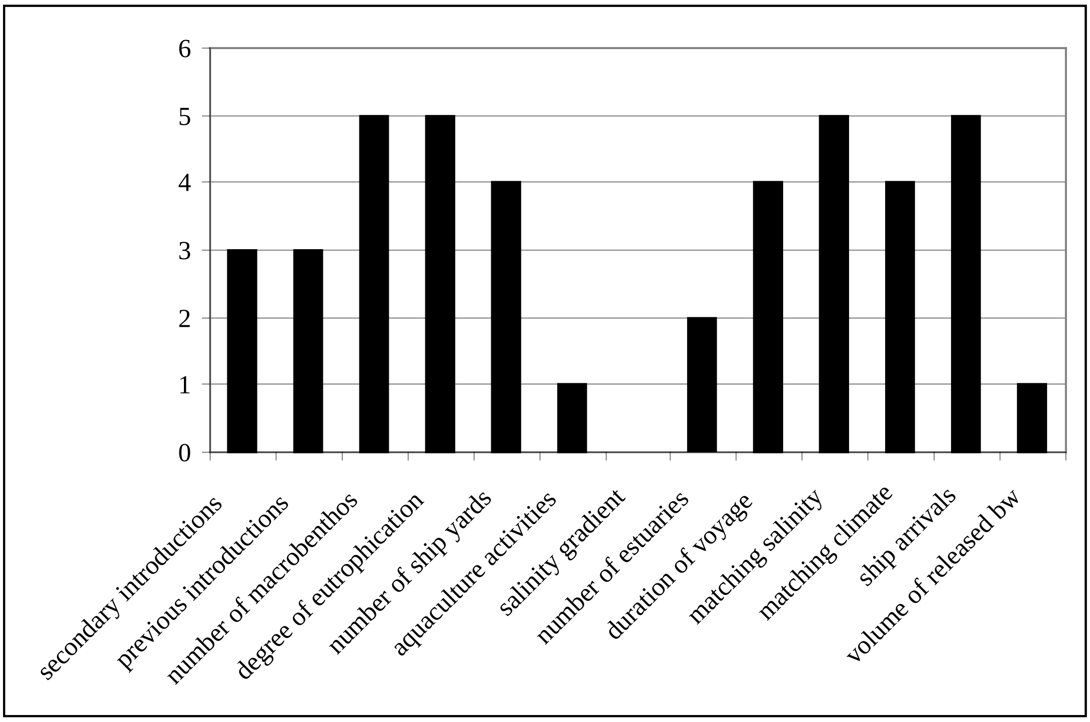


Figure 7. Risk factors estimating the risk of the fresh water port St. Petersburg.

17.5. Summary of risk assessment

The unique situation of the Nordic countries enables a risk assessment from freshwater to marine habitats. The potential for further species introductions in freshwater is probably. This is due to the fact that most of the important shipping routes to the Nordic countries call for ports in marine or brackish water regions. Therefore, the amount of introduced freshwater ballast is comparably lower than ballast of marine or brackish origin. Predominantly matching climates and salinity conditions in donor and recipient regions, combined with a high number of ship arrivals, increase the risk for species introductions.

Table 3. Summary of risks of future species introductions by ships according to prevailing salinities in the region (N = Nordhordaland, K = Klaipeda, SP = St. Petersburg, ST = Stenungsund and T = Turku).

Summary of risks			
	Salinity		
Risk level	Freshwater	Brackish water	Marine water
low			
medium - low	ST		
medium	K, T	ST	K, ST, T
high	SP	K, T	N
extremely high			

For the purpose of this report, we can only estimate the risk for future species introductions based on the five ports listed above, due to the lack of data from neighbouring areas. The risk for future species introductions by ships was classified, by the above mentioned parameters, in:

1. **extremely high risk**: anthropogenic impact (high number of fish processing plants, aquaculture activities), estuarine to marine port areas with high amount of released ballast water from areas of matching climate and salinity (**none** of the listed port regions)

2. **high risk**: anthropogenic impact (high number of fish processing plants, aquaculture activities), estuarine to marine port areas with medium amount of released ballast water mostly from areas of matching climate or salinity (**St. Petersburg** for freshwater introductions, **Klaipeda** and **Turku** for brackish and **Nordhordaland** for marine introductions)

3. **medium risk**: estuarine port areas with medium amount of released ballast water (**Klaipeda** and **Turku** for freshwater introductions, **Stenungsund** for brackish water and **Klaipeda**, **Stenungsund** and **Turku** for marine introductions)

4. **medium - low risk**: freshwater port areas with little amount of released ballast water and a little number of incoming vessels, limited number of shipping routes to areas of matching salinity and climate (**Stenungsund** for freshwater introductions), and

5. **low risk**: freshwater port areas with no/very little amount of released ballast water and little anthropogenic influence. Shipping routes to non-matching areas of salinity and climate (**none** of the listed port regions).

NIS may invade marine, brackish as well as freshwater habitats. Therefore, St. Petersburg with its freshwater conditions is in the same way open for introductions of alien species as the ports of western Norway.

The calculated risk factors for all port regions investigated vary from 25 to 40. The comparison of the port regions reveals that the area of the highest risk (risk factor 40) for the introduction of a marine species is Nordhordaland followed by St Petersburg (risk factor 39) for the introductions of freshwater organisms. Stenungsund (risk factor

35), Klaipeda (risk factor 39) and Turku (risk factor 37) are of high risk to receive brackish water species.

Furthermore, it is concluded that the establishment of fish farms along major shipping routes needs to be avoided. In the case of the Norwegian west coast, where fishfarms have been established in these areas, introduced species may cause severe economic harm. Additionally, the extensive fish culturing in the area represents a habitat for NIS parasites. An introduced parasite, e.g. a sea lice, could cause dramatic losses in the fishing harvest. In 1996 in the Hordaland area (Norway) the value of the farmed salmonids was 1.4 billion NOK. The traditional fishing fleet could be negatively affected by an introduced open water species. The value of landed fish is 1.07 billion NOK.

The unwanted scenario of an introduced parasite species turned into reality along the Chilean coast, as a sea lice was introduced in 1990s. As no living fish was introduced, the vector of introduction could have been the ballast water of ships (H. Rosenthal, pers. comm.).

It is important to notice, that this risk assessment does not represent an overall perspective, but focuses on potential future NIS introductions by ships ballast water, tank sediments and ship hull fouling. Taking into account other introducing vectors (e.g. migration of species via canals and waterways), the Port of St. Petersburg will probably be considered an extremely high risk area due to the influences of major canals in the area. Intentional introductions for restocking purposes of invertebrates in adjacent fresh water reservoirs would probably bring the port of Klaipeda into focus.

This first, initial risk assessment of selected Nordic port areas, documents a tentative estimation of the risk for further species introductions. Due to the lack of data no risk assessment on a broader scale was possible. The port profiles are the first step to summarise data relevant to the issue. Monitoring of additional port areas would assist to widen this risk assessment and to fill in the white gaps on the map.

18. Gaps identified, further research needed

Much remains unknown in terms of the patterns and processes of invasions. In the need to establish risk assessment protocols and effective management plans, there are large gaps remaining in the knowledge (Box 17). The following list summarises examples of important research needs and applications.

1 Further studies on the ecology of introduced species

Only a few of the NIS have been studied experimentally or in a wider ecosystem context. The exact impact of NIS on native ecosystems can only be quoted if more details on their requirements and relationships to the native biota are known.

2 Shipping studies and port profiles

A more intensive biological and ecological study of major ports and the ballast water arriving in the Nordic waters is urgently needed. A regional shipping study would provide basic data for management plans and guidelines to deal with ballast water.

The provided information on the port profiles enabled a first, initial risk assessment for the potential of further species introductions to selected areas in the Nordic coastal waters. Relevant data on additional port areas are essential to assess the risk in more detail in the future.

3 Economic impacts of wood borers and fouling organisms

Impacts of wood-boring organisms (shipworms and isopods) and of fouling organisms (on vessels and submerged installations) are widely unknown and remain largely undocumented and entirely unquantified in Nordic countries.

4 Genetic studies of introduced species

The application of modern molecular genetic techniques has already revealed the cryptic presence of previously unrecognised invaders in the San Francisco Bay area (Cohen & Carlton 1995). European studies on the polychaete *Marenzelleria* revealed that in fact two, morphologically very similar species *M. viridis* and *M. wireni* did invade. *M. viridis* is predominantly found in the Baltic Sea and *M. wireni* in the North Sea (Bastrop *et al.* 1997, Bick *et al.* 1997, Schiedek 1997, Schiedek *et al.* 1997, Zettler 1997a, b).

The objective to evaluate "hot spot donor areas" of future species introductions may be determined more precisely by genetic comparison of previously introduced species. In this way the origin (native range or introduction from a habitat formerly invaded) of the introduced species can be proven.

5 Post-invasion control mechanisms

Studies on potential control mechanisms (e.g. biocontrol, physical treatment, eradication) of harmful introduced species are in their initial phase. Currently pilot studies are undertaken in order to control *Carcinus maenas* in Tasmania and *Mnemiopsis leydii* in the Black Sea and for *Caulerpa taxifolia* in the Mediterranean Sea.

If it is impossible to eradicate a new invader completely, it might be possible to prevent or slow down its further (secondary) post-invasion spread. Public awareness programmes may assist in slowing down the process of spread of *Caulerpa taxifolia* in the Mediterranean Sea and the zebra mussel in the North American Great Lakes and in Ireland.

6 Additional risk assessments

As each single vessel has the potential to introduce a new species, it is not meaningful to estimate the total amount of ballast water discharges. In order to evaluate the risks in a Nordic perspective, it would be helpful to know all potential source areas of ballast water outside the Nordic area.

The establishment of a network of experts, institutions and authorities would support the effectiveness of future risk assessment studies by transferring knowledge between working groups.

Box 17

WHAT is needed?

- establish a network in order to spread information, including an effective warning system in order to document and possibly control/prevent secondary introductions within the Nordic countries
- develop a database listing known and expected introduced species
- monitoring programmes (including studies on the ecology of introduced species)
- further research on the community structure and invasibility of native habitats
- advanced methods for risk assessment, shipping studies and port profiles
- economic impacts of introduced species (e.g. wood borers and fouling organisms)
- genetic studies of invaders
- research on post-invasion control mechanisms
- development of further efficient, applicable, cost effective, environmentally safe and sound treatment options of ballast water
- cost/benefit analysis for planned introductions
- co-ordination of research interests to avoid overlapping work

There are no specific monitoring programmes for NIS in the Nordic or Baltic Sea area. However, programmes carried out within the HELCOM system, as well as national monitoring programmes for bottom fauna and plankton, do produce overviews on changes in the environment. These programmes could support the control of introduced and/or established NIS.

18.1. Conclusions

No part of the Nordic seas is protected for future alien species introductions. The special Baltic Sea conditions as a brackish water body will not prevent the introduction of NIS: there are approx. 90 NIS recorded from the Baltic Sea (incl. the) of which approx. 70 can be regarded as established parts of the biotic community (Leppäkoski & Olenin in prep.) (consult the database on alien species in the Baltic Sea at http://www.ku.lt/nemo/mainemo.htm). A potential new invader can be any species invading any sort of habitat.

Window of introduction

It is false to say that every species that could have been introduced would be here now. For example, there have been shipping routes from the Caspian and Black Sea region to the North American Great Lakes for many decades, before the zebra mussel *Dreissena polymorpha* was finally successfully introduced to this area. It took several decades to "open" the window of introduction, i.e., to catch the right conditions in both donor and recipient areas and a vessel releasing ballast water containing a sufficient number of zebra mussel larvae at the same time.

The chance of an introduced species to become established and the chance for this introduced species to become a serious problem for the environment or economy is small. However, one single introduced species can cause severe harm to the economy and ecosystem the species invades, as shown by the zebra mussel in the North American Great Lakes, the comb jelly in the Black Sea and the green seaweed *Caulerpa taxifolia* in the Mediterranean Sea.

Risk assessment

Our current knowledge indicates that anthropogenically supported invasions in aquatic ecosystems increase on a world-wide basis. Many other aspects of invasions remain nearly unpredictable. Among them, unfortunately, are the most wanted answers to 1) which species will invade, 2) when will it invade, 3) where will the species invade, and 4) what will be the impact of this new species? Today these questions can be answered only on a theoretical or broad scale. Accordingly, an indication of habitats at risk can be given only on a limited base. We know that certain areas such as estuaries and areas with high input of NIS (ports, waterways and shipping routes as well as aquaculture sites) represent high risk areas for further introductions. Taking into account the shipping routes, and comparing matching salinity and climate conditions in donor and recipient area, the first incomplete estimations are made. Adding the duration of the ships voyage (a short term voyage will increase the survival rate of specimens in the ballast tank) the picture becomes more clear, but is still far from a prediction and represents a kind of an advanced guess.

Network

The establishment of a network of experts, institutions and authorities would support the effectiveness of future risk assessment studies by transferring knowledge between working groups. In this way an effective warning system, in order to document and possibly control/prevent secondary introductions within the Nordic countries, could be installed. This would face different aspects that are needed to undertake a positively overlapping risk assessment.

Control of occurring introduced species

Future invasions may include large negative financial impacts enforcing the need to take action in order to prevent or at least minimise/control the number of future introductions. Eradication methods of unwanted introduced species are costly, often not highly effective and for vegetatively propagating species they may increase their dispersal. In some cases, the intentional introduction of a new species (predator, competitor, parasite or disease agent) has been discussed in order to eradicate an unwanted invader (biocontrol). In some cases it has been successful, but in others the trial has failed completely. The biocontrol species needs to interact exclusively with the target species. Otherwise native species will be eradicated as well.

On the other hand the application of chemical treatment of the unwanted organisms by adding substances to the water is in use to control the population density of e.g. the sea lamprey (*Petromyzon marinus*) in the North American Great Lakes (Morse 1990).

Both the biocontrol and chemical treatment methods need to be studied intensively in regard to 1) identify a useful species or substance; 2) test the specificity of the treatment (to prevent negative effects on native non-target species); and 3) evaluate the risks of the bio-control species to interact with native species unknown in the area of origin of the bio-control species. For three years Australian researches have been looking for an effective and specific agent to treat the harmful Pacific starfish (*Asterias amurensis*) and the European green crab (*Carcinus maenas*). Promising trials are underway, but still after years of research it is not clear if the biocontrol agent will not threaten any native species (ICES Report of the Study Group on Marine Biocontrol of Invasive Species 1997, Thresher pers. comm.). Moreover, tests have been carried out in the laboratory for the tropical green alga *Caulerpa taxifolia*, as well as for purple loose strife and the Eurasian water milfoil (Wallentinus pers. comm.).

In addition, after the hypothetically successful trial, the newly introduced biocontrol species needs to be eradicated. Furthermore, not all unwanted species introductions can be managed in this way. Therefore, the money spent to prevent future introductions will pay off in the longer run due to the prevention of costs to manage impacts of uncontrolled introductions.

Ballast water management

Management practices (e.g. the ballast water exchange in open sea) are the first step to minimise the risk associated with species introductions. Especially in the case of the Baltic Sea and other brackish water areas, such as the Black Sea, river mouths and diluted waters of inner parts of fjords and coastal inlets, the ballast water exchange in highly marine water with oceanic salinity represents a practicable and cost effective method reducing the risk of further species introductions. Some oceanic species might, however, have the capacity to tolerate brackish salinities. On the other hand many ships may not pass such areas en route and a Scottish study (Macdonald 1998) indicated that the number of species may in fact increase on short routes within Europe. If the IMO guidelines on how to ballast and how to exchange the ballast water are followed, it will minimise the risk of further introductions without any reconstruction of ships.

Strategies to implement the IMO guidelines are needed. Regional authorities shall promote to implement these guidelines as legally binding provisions. It is important to note that the IMO guidelines do not solve a long term solution to the problem of ship mediated species transport; ballast water issues must be given high priority when designing the new generation of ships.

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Appendix 1, Definitions

Sources:

(1) IMO Assembly Resolution A.774 (18) for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens

(2) Code of Practice of the International Council for the Exploration of the Sea (ICES), Working Group on Introductions and Transfers of Marine Organisms WGITMO

(3) draft IUCN Guidelines for the Prevention of Biodiversity Loss due to Biological Invasions

(4) Carlton (1996)

(5) draft Risk Assessment Protocol for the Introduction on Nonnative Species of Fish. Regional Nonnative Species Introduction Committee, Winnipeg, Manitoba. October 1996

(6) AQIS report No. 9. Ballast water - Technical overview report (1996)

(7) Committee on Ships´ Ballast Operations. Marine Board, Commission on Engineering & Technical Systems, National Research Council (1996): Stemming the tide: controlling introductions of nonindigenous species by ships´ ballast water.

Definitions:

"Alien species" see "Introduced species"

"Country of origin" is the country where the species is native (2)

"Disease agent" is understood by mean all organisms, including parasites that cause disease (2)

"Established species". Species occurring as a reproducing, self-sustaining population in an open ecosystem, i.e. in waters where the organisms are able to migrate to other waters (5)

"Exotic species" see "Introduced species"

"Intentional introduction" is a deliberately made introduction by humans, involving the purposeful transport of a species or subspecies (or propagules thereof) outside its natural range. Such introductions may be either authorised or unauthorised (3)

"Introduction" An introduction of an organism is the dispersal, by human agency, of a living organism outside its historically known range (3)

"Introduced species" (= alien species, = exotic species, nonindigenous species) Any species intentionally or accidentally transported and released by humans into an environment outside its present range (2).

“Marine species” is any aquatic species that does not spend its entire life cycle in fresh water (2).

"Native species" is a species, subspecies or lower taxon, occurring within its natural range and dispersal potential (i.e. within the range it occupies naturally or could occupy without direct or indirect introduction by humans) (3)

"Nonindigenous" see "Introduced species"

"Secondary introduction" is one that takes place as the result of an intentional or unintentional introduction into a new area and the species disperses from that point of entry to other areas that it could not have reached without the initial (primary) human mediated introduction (3)

"Transferred species" (= transplanted species) Any species intentionally or accidentally transported and released within its present range (2)

"Translocation" Movement of native or introduced species to habitats outside its historically known range (6)

"Treatment" means a process or mechanism, physical, chemical or biological method to kill, remove or render, harmful or potential harmful organisms within ballast water (1)

"Unintentional introduction" is one made as a result of organisms utilising humans or human transport systems as vector for dispersal into new areas. The introduction is incidental to the main transaction taking place (often trade and in the marine environment aquaculture) (3)

19. The ports of western Norway – Bergen, Eikefet, Ågotnes, Mongstad and Sture

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19.1. Introduction

This paper reports on the ship traffic and release of ballast water in the harbours of Bergen, Sture, Mongstad, Ågotnes and Eikefet in the Bergen area on the west coast of Norway (Fig. 1). Introductions of alien species via ballast water may represent a serious threat to the marine environment in general and some specific industries in particular. Thus we have attempted to quantify some of the values at risk, such as those of aquaculture and traditional fisheries.

During the last few decades oil export form Norway has increased tremendously. Oil tankers of considerable size arrive every day to western Norway in ballast to load crude oil or refined products. Given the size of the vessels, the regularity of arrivals and the amount of ballast water carried on each voyage, oil tankers alone bring in most of the ballast water released in west Norwegian harbours on annual basis. Although other ship types are numerous they carry and release less ballast water. Releasing of small amounts of ballast water is, however, no guarantee of not transferring nonindigenous species (NIS) to Norwegian waters.

19.2. Bergen harbour throughout history

Norway's long coast with its busy maritime activity involving fishing, trade and communication is the basis for Norwegian shipping. A vast exchange with foreign countries is a vital. The harbour of Bergen, and in particular its oldest part, Vågen, has been one of the most important trading junctions in the country since the 12th century, attracting trade of stockfish from northern Norway for grain and other essential goods. Large ships carried out the trade between Bergen and foreign countries. Ever since the law of King Magnus Lagabøte of 1276, Bergen has had formal legislation in order to regulate and oversee the traffic and physical development of the harbour area. For instance, the law of 1276 regulated the disposal of dry ballast to prevent Vågen from getting filled in (Fossen 1985).

Figure 1. The location of the harbours at Bergen, Ågotnes, Eikefet, Sture and Mongstad on the Norwegian west coast.

In addition to the royal decree granting certain Norwegian towns a monopoly on local and foreign trade, Bergen's favourable location made it the first international trading centre in the Nordic countries and Norway’s largest and most important town during the Middle Ages. The town functioned as a mart (for shipping lay-up, transhipping and as a marketing place) for trading between northern Norway and the islands to the west (Iceland, Greenland, Faeroes and the Shetland Islands) and important ports in Europe. However, most of the foreign trade with Bergen until the mid 1600's was carried out by foreign ships. The Hanseatic League in particular played a significant role through its extensive trade with ports on the Continent and the British Isles such as Lübeck, Danzig, Riga, Antwerp and London.

After the mid 1600's the shipping activity originating in Bergen increased even further and gradually the ownership of most ships was taken over by Norwegians. Although the town lost its status as the biggest port in Norway to Kristiania (Oslo) in the mid 1800's, it was still a major international port handling articles such as fish, grain and salt. Most of the Norwegian mercantile fleet was built or purchased with export of its own products in mind. However, it was not unusual that ships from Bergen could be engaged in the carrying trade between foreign ports. It often occurred that freighters from Bergen transported goods in the Mediterranean before returning to Bergen for reloading.

The port of Bergen has undergone several significant expansions during the 20th century. Today it is part of a port district called "Bergen og Omland havnedistrikt", Norway's largest and most active. It is also the country's most important port of call for cruise ships with 159 calls and almost 76 000 cruise passengers in 1993, and ferrying about 134 000 passengers to and from Bergen. The amount of cargo that was loaded and unloaded were 68 797 410 tons during the course of 19 291 ship calls in 1993. This entire tonnage was in total almost 60.4 million gross tonnage, the greatest amount of goods handled in any port area in the Nordic countries that year. Most of the traffic is due to the activity at the oil terminals at Sture and Mongstad, the Mongstad refinery, the supply base Coast Centre at Ågotnes and various smaller ports in the harbour district (Hartvedt 1994).

19.3. Abiotic and biotic conditions in the Bergen harbour area

Norway has a coastline with many fjords. A fjord can be regarded as a complex estuary connected to the coastal water with one or more sills. The depths of the fjord basins of the Bergen harbour area vary from 350 m (Byfjord) to 650 m (Osterfjord) and the deepest sill is 170 m (Helle, 1978). In some parts of the fjords there are landlocked inlets called polls, with extremely shallow sills (Syvitski, 1987).

The temperature of the surface layer (0-5 m) normally varies from 3 ^{o}C in winter to 15 ^{o}C in late summer (Fig. 2). In cold winters a thin ice sheet may cover the polls. The salinity of the Norwegian Coastal Current is about 35.5 ‰ (Helle 1978) and the salinity gradually declines toward the inner fjords and polls. The low salinity (26-27 ‰) in the outer fjords during summer, suggests dilution by less salty water from the inner fjords (Fig. 2). Inner fjords typically have low surface salinity due to fresh water run-off during summer. During summer the decline in salinity coincides with the maximum temperature of the fjords. The heavy rainfall in western Norway, especially during autumn, may affect the salinity. Polls may show distinctive hydrographic features arising mainly due to fresh water discharges, replacement of deep water and winds.

In the Bergen harbour area the occurrence of nutrients in the surface layer (0-5 m) varies during a year (Hydrographic data 1987-1997, Risheim *et al.* 1993). Low light intensity in the winter inhibits plankton growth, with a concurrent high concentration of nitrate (NO_3^-) and phosphate (PO_4^{3-}) from November to March, peaking in January (7.71 μM NO_3^- and 0.46 μM PO_4^{3-}). During spring, higher light intensity enhances the primary production, which reduces the concentration of nutrients. Low concentrations of nitrate and phosphate are most pronounced in August (0.09 μM NO_3^- and 0.06 μM PO_4^{3-}) (Risheim *et al.* 1993).

The fjord basins have estuarine circulation. The outflow of light surface water is gradually being mixed with underlying salt water. An inward flow of coastal water above the sill replaces the outflowing water. Wind, tidal currents and turbulence may modify this pattern.

The deep-water renewal of fjord basins is dependent on winds and currents along the Norwegian coast. The direction of the Norwegian coastal current varies according to seasonal changes in wind pattern. Due to the Coriolis effect, the wind from north pushes coastal surface water away from the coast causing upwelling of dense, oxygen saturated and nutrient rich bottom water at the sills. During winter the processes of entrance and upward vertical diffusion of salt in the fjord basins, leave the deep water less dense. This event leads to the opportunity of deep-water renewal by the upwelling water. At the west coast of Norway deep water replacement usually takes place in spring or early summer due to the wind pattern along the coast. Fjords with shallow sills exchange deep water in winter or spring and those with deeper sills in the summer (Helle 1978, Gade & Edwards 1980, Syvitski 1987, Hydrographic data 1987-1997). The polls show the same tendency of deep-water exchange, though not necessarily every year.

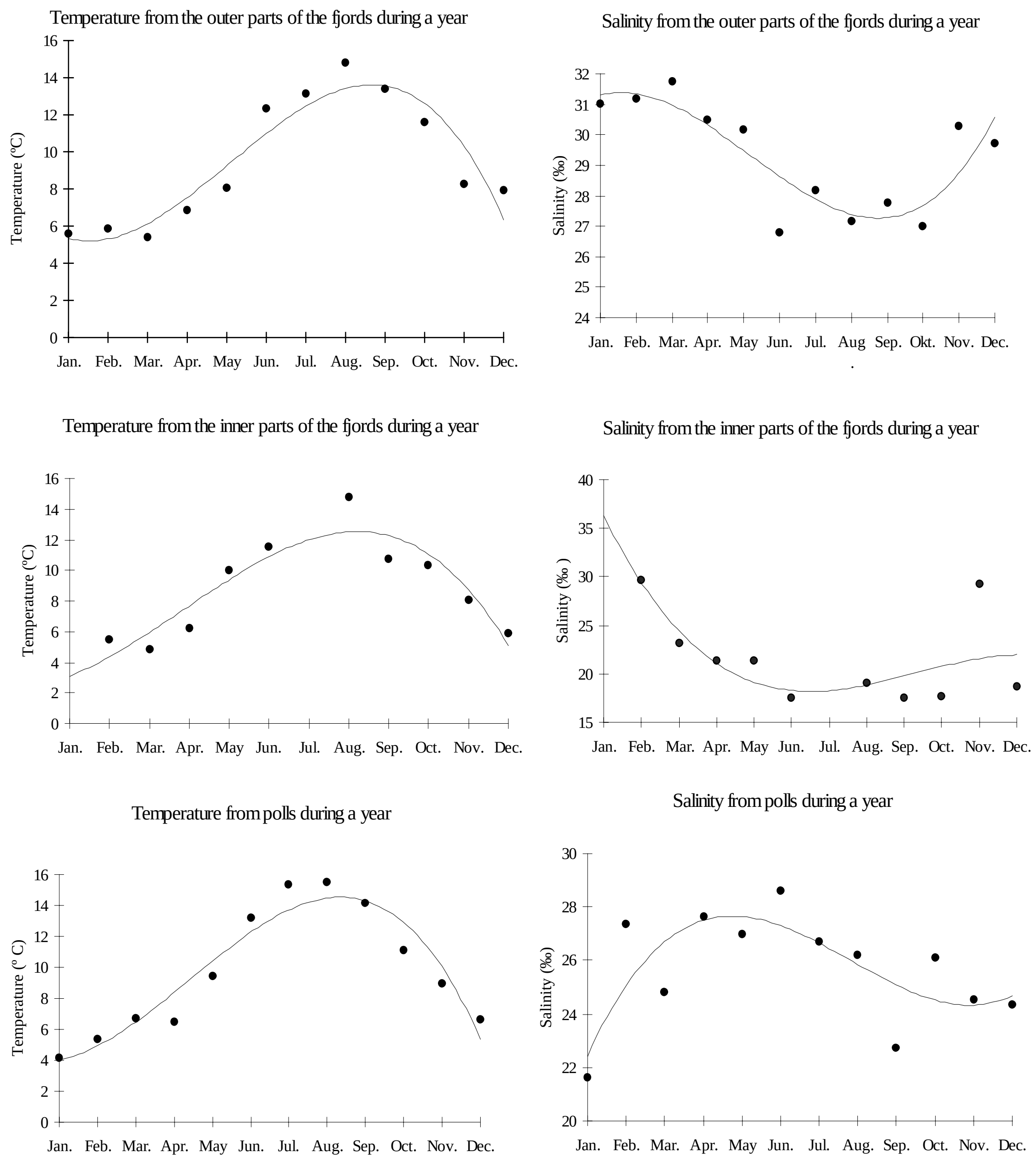


Figure 2. Hydrographic features (temperature and salinity) from the surface water (0-5 m) of typical fjords surrounding Bergen harbour area. Data from 1987-1997.

In periods of stagnation, bottom fauna and bacteria of land-locked fjord basins and polls deplete the oxygen in the sediments. In sediments with no free oxygen, sulphate reducing bacteria produce H_2S that will leave the bottom sediments barren of fauna. A replacement of the deep water with oxygen saturated dense water will re-establish the fauna.

There are ca. 2 500 species of marine benthic macro-organisms in the county of Hordaland (Brattegard & Holthe 1997). The various habitats within a fjord basin make up a diverse fauna and flora. These habitats can vary from soft to rocky sediments, exposed to sheltered littoral zones, and varying salinity regime. Normally the biodiversity declines from the outer to the inner parts of a fjord system (Brattegard & Holthe 1997).

There are 73 benthic species (1 plant species and 72 invertebrate species) of unknown distribution in Hordaland county area (Brattegard & Holthe 1997) (Fig. 3); these cryptogenic species may be unknown due to insufficient knowledge or lack of revision of existing material.

The various habitats support different species communities. Common species, in a soft sediment community with good environmental conditions, are polychaete worms (e.g. *Spiochaetopterus typicus*, *Ceratocephale loveni*, *Tharyx* sp., *Lumbrineris* spp., *Paramphinome jeffreysi*), molluscs (e.g. *Thyasira equalis*, *Nucula tumidula*, *Kelliella miliaris*), crustaceans (*Eriopisa elongata*), sipunculans (*Onchneosoma steenstrupi*) and ophiuroids (*Amphilepis norvegica*). Soft sediments are mainly found in sheltered areas and in the deeper parts of the fjords. Land-locked polls and fjords with poor circulation have very soft sediments with a high organic content, characterised by few species with many individuals. These are often opportunistic species such as polychaete worms (e.g. *Polydora ciliata*, *Glycera alba*, *Chateozone setosa*, *Capitella capitata*, *Heteromastus filiformis*) and molluscs (e.g. *Thyasira sarsi*, *Corbula gibba*) (Johannessen *et al.* 1990, Botnen *et al.* 1996).

Shallow, exposed sounds near the coast often contain more rocky sediment or shell debris. Tidal currents can be strong in these areas. Common species are molluscs (*Modiolis modiolus*, *Astarte* sp.), seafish, (*Henricia* sp.), ophiuroids (e.g. *Ophiocomina nigra*, *Amphiopholis squamata*), echinoids (e.g. *Echinus* sp., *Echinocyamus pusillus*) and some polychaete worms (e.g. *Chaetopterus variopedatus*, *Pomatoceros triqueter*, *Typosyllis* sp.) (Fjellstad & Høisæter 1991).

In the littoral zone the algal cover extends to around 20-30 m depth. There is a characteristic zonation of algae and animals that varies according to the degree of exposure. In sheltered areas the upper shore has channelled wrack (*Pelvetia canaliculata*), spiral wrack (*Fucus spiralis*), and knotted wrack (*Ascophyllum nodosum*), while the lower shore has toothed wrack (*Fucus serratus*) and sugar kelp (*Laminaria saccarina*). Bladder wrack (*Fucus vesiculosus*) is typical of more exposed areas. Dabberlocks (*Alaria esculenta*), *Porphyra umbilicalis* and other species of red algae dominate the most exposed areas. The kelp *Laminaria hyperborea* usually dominates subtidally (Hawkins *et al.* 1992).

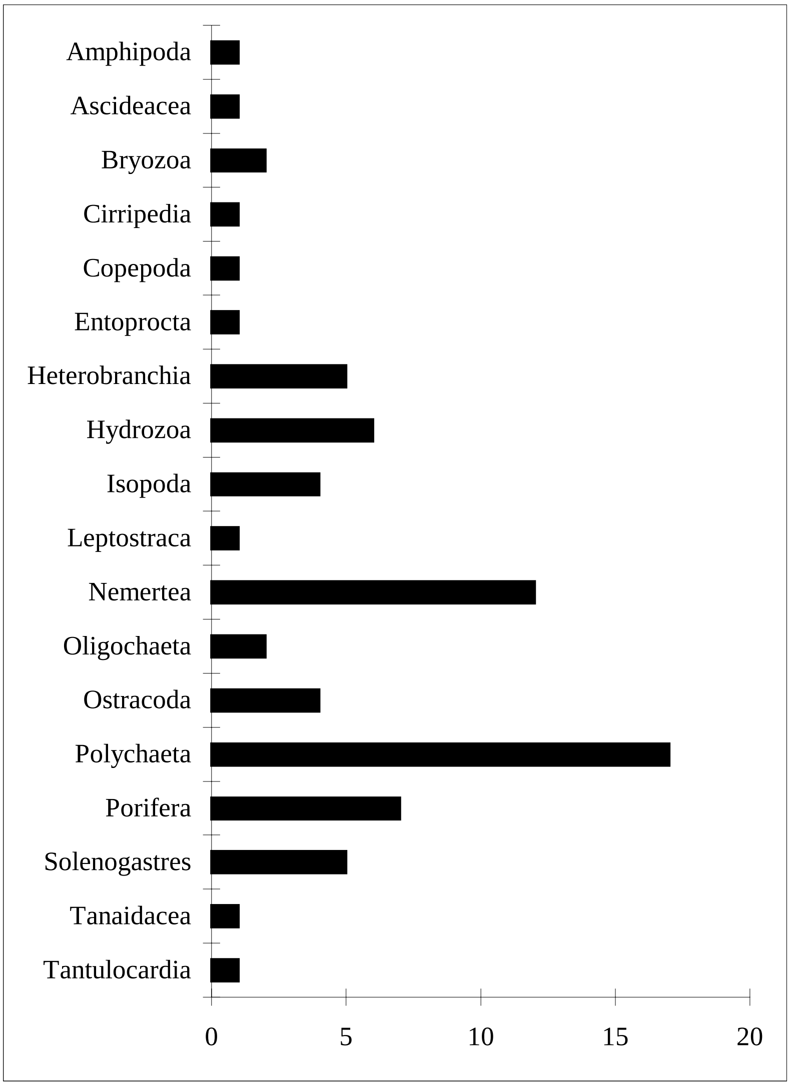


Figure 3. Possible number of cryptogenic species in Hordaland. Numbers from Brattegard & Holthe (1997).

Periwinkles (*Littorina* sp.), limpets (*Patella* sp.), dogwhelk (*Nucella lapillus*), polychaete worms (e.g. *Spirorbis* sp., *Pomatoceros triqueter*), crabs (*Carcinus maenas*) and sea urchins (*Echinus* sp.) are common animals in the littoral zone. At more exposed sites, barnacles (*Balanus* sp.) and blue mussel (*Mytilus edulis*) are more pronounced.

The mass occurrence of large individuals of the jellyfish *Perifylla perifylla* is a peculiar phenomenon in Lurefjord outside Bergen. Normally, this is a deep oceanic species dominated by small individuals (Fosså 1992).

19.4. Traffic statistics

The volume of the traffic can give a rough indication of the amount of ballast water dumped in the harbours around Bergen. In total about 17 100 arrivals were registered in the harbours of Sture, Mongstad, Eikefet and Bergen in 1996 (Fig. 4). Of this about 70 % had a Norwegian harbour as the last port of call before arriving. Altogether about 89 million GT arrived, of which about 18 % had a Norwegian harbour as last port of call (Fig. 5). A large number of small passenger vessels and coastal ships, and a large number of domestic fishing boats delivering their catches in Bergen cause the mismatch between the arrivals and tonnage. The international traffic is mainly from harbours in England, the European Continent and the Nordic countries from reloading harbours like Antwerp, Rotterdam, Wilhelmshaven and Hamburg. A few oil tankers arriving at Mongstad and Sture come from the Black Sea, North America, Caribbean and Australia (Fig. 6). The traffic at Ågotnes is concentrated on the oil and gas activity in the North Sea. Aggregates is exported from Eikefet to the Continent and England, and about 80 % of the international traffic arriving comes from Wilhelmshaven and Rostock.

There seems to be no seasonal pattern in the shipping traffic, although there is somewhat lower activity during December to April at Eikefet.

The amount of ballast water released in the harbours varies. Almost every ship arriving at Sture, Mongstad and Eikefet arrives in ballast. At Sture crude oil is shipped out, while at Mongstad crude oil is shipped both in and out in addition to refined products which are shipped out. Aggregates are shipped from Eikefet. Ballast release at Sture was estimated to about 13.5 million tons in 1996 (Morten Glitre pers. comm.), whereas about 7.2 million tons were released at Mongstad (Jon L. pers. comm.). Only fair estimates at Eikefet are possible. Both at Mongstad and Sture records of volumes of shipping traffic and last port of call are kept for the vessels arriving. Dirty ballast, ballast that has been carried in cargo hauls of the oil tankers, is pumped to a treatment plant for removal of oil pollution prior to release in both harbours.

Accurate estimates for Bergen and Ågotnes are difficult, but the amount of ballast water released is probably significantly smaller than at Sture and Mongstad. This is a result of that the arrivals at Bergen are different types of passenger ships. Although cargo, ro-ro ships, bulk and tankers are important contributors to the traffic these may often come loaded and leave loaded and thus release only small amounts of ballast water. Ågotnes is a harbour for shipping of supply to the oil and gas industry in the North Sea. Vessels operating at Ågotnes often leave for the oil fields with cargo and bring cargo back from the platforms, thus having a limited need for ballast.

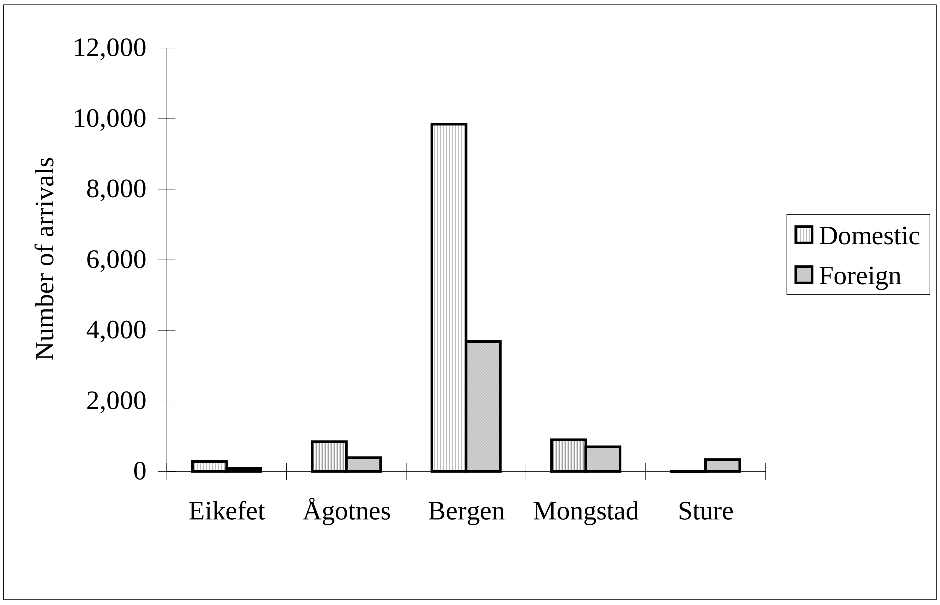


Figure 4. Number of arrivals at Eikefet, Ågotnes, Bergen and Mongstad in 1996. Numbers for Sture from 1993. Domestic indicates number of calls from Norwegian ports, international indicates number of calls from ports outside Norway.

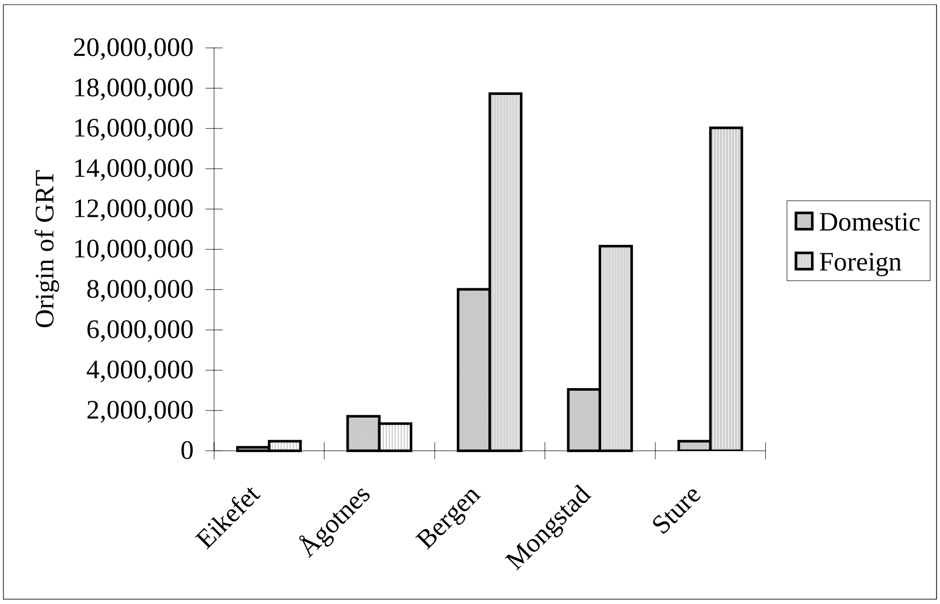


Figure 5. GT arrived at Eikefet, Ågotnes, Bergen, Mongstad and Sture in 1996. Domestic indicates GT from Norwegian ports, international indicates GT from ports outside Norway.

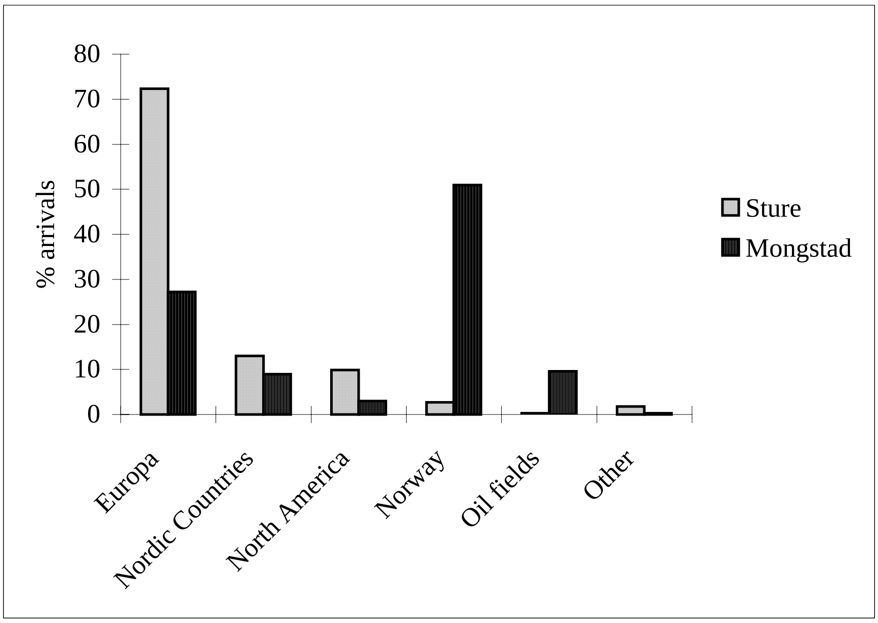


Figure 6. Last geographic region of call prior to arrival at Sture and Mongstad. Numbers from Sture in 1993, numbers from Mongstad in 1996.

19.5. Introduced species

Existents and distribution of non-indigenous species in Norwegian waters are generally poorly investigated. A list of known introduced species compiled from Tømmerås (1994), Brattegard & Holte (1997) and Jansson (1994) contains 18 species that might have been introduced or expanding their range into Norwegian waters after being introduced to adjacent areas (Tab. 1). Of these *Codium fragile, Sargassum muticum, Balanus improvisus* and *Teredo navalis* are registered along the coast and *Crassostrea* spp. and *Ruditapes philippinarum* in aquaculture sites in Hordaland. *Crassostrea* spp. and *Ruditapes philippinarum* outside aquaculture sites are not yet discovered, although the species are able to spawn (Mortensen pers. comm., Mortensen & Strand in prep.).

A thorough examination of the Norwegian marine flora and fauna should be made before the exact number of introduced species can be established. This examination should comprise biogeography and include the fauna in Shetland, Scotland and the northern part of the North Sea. These should be included since juvenile stages of species from these areas are able to establish populations at parts of the Norwegian coast for some period of time. These species could misleadingly be considered as introduced species, although the most important vectors for such establishments are short-term variations in the Norwegian coastal current and inflow of water from the North Sea and the Atlantic Ocean.

19.6. The Sture Project

The first ballast water study in Norway started at the oil terminal at Sture in April 1996 and continued until September 1997. Most of an annual cycle is covered in the sampling programme which was also designed to take into account the origin of the ballast water, and collected ballast water from 30 vessels from all major geographic areas. Analysis comprised phytoplankton and zooplankton as well as abiotic measures such as temperature, salinity, oxygen content and nutrients. Samples were normally collected through the man hole on deck by water sampler and dip net. Some preliminary results from the Sture investigation are given below.

Oxygen content in the ballast water was always high and above 4.7 ml O_2/l (Tab. 1), which is sufficient to support aquatic organisms. The salinity varied from 1 to 36.8 S (Tab. 1). Species surviving transfer in low salinity have little chance of survival at Sture, where the salinity normally is between 29 and 30 S in the surface and higher at deeper water. Vessels carrying low salinity ballast water to Sture came from the Baltic, Antwerp and Philadelphia in the US.

Table 2. Preliminary results from the ballast water investigation at Sture in western Norway. Measurements of ballast water. Sea summer and winter values indicate the upper limit of the best environmental conditions in Norwegian coastal and fjord waters (Rygg & Thélin 1993).

Parameter	Range in ballast	Sea summer	Sea winter
Temperature (°C)	5.5 - 23.4		
Salinity (S)	1 - 35		
Oxygen content (ml O_2/l)	4.8 - 9.8		
Orto-phosphate (µg/l)	6 - 670	4	16
Total phosphor (µg P/l)	11 - 755	12	21
Nitrate-N (µg/l)	12 - 2910	12	90
Total nitrogen (µg/l)	65 - 7800	250	295

The nutrient content in the ballast water was high compared to levels normally measured along the west coast (Tab. 1).

All but one of the investigated vessels contained live organisms despite voyages lasting up to 18 days. Live phytoplankton were present in 96 % of the vessels (Fig. 7). Copepoda and Cirripedia were frequent in the samples too, whereas Polychaeta and fish eggs were less frequent. Other taxonomic groups are present in the samples and live fish and crabs have been observed in the ballast tanks during sampling.

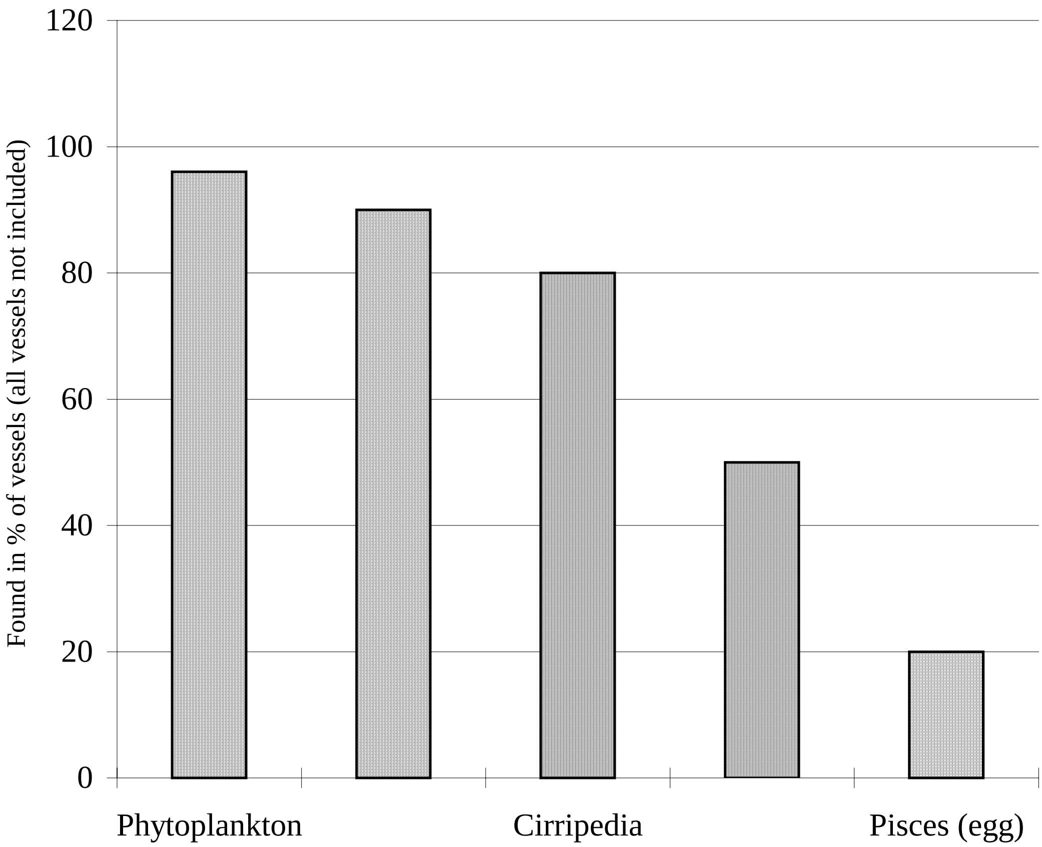


Figure 7. Percentage of samples (vessels) containing live phytoplankton, Copepoda, Cirripedia, Polychaeta and fish egg. Preliminary results from the ballast water study at Sture.

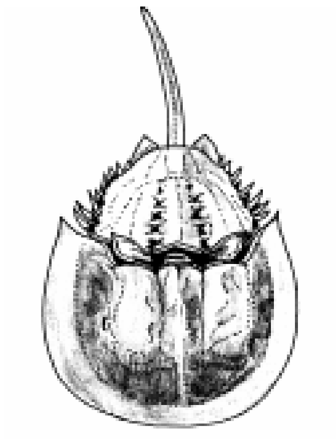
19.7. Marine resources at stake

The most susceptible industries in Hordaland for introduced marine organisms are fish farming and traditional fisheries. Fish farming is a major industry in Hordaland and dependent on good marine environmental conditions. Atlantic salmon (*Salmo salar*) and rainbow trout (*Onchorhyncus mykiss*) are the main species in fish farming, and halibut (*Hippoglossus hippoglossus*) is a potential new species for farming. There is growing interest in culturing of scallop (*Pecten maximus*) and oyster (*Ostrea edulis*) in Hordaland, and scallop spat production is now close to be commercialised.

In total almost 300 marine sites are used for fish farming, and in 1996 about 66 000 tons of salmon and 7 000 tons of trout were produced. The value of fish is estimated at 1.4 billion NOK (Anon. 1996). Fish farms close to harbours where ballast water is released are assumed to be particularly susceptible to any introduced or transferred disease or parasite, although a higher prevalence of disease in fish farms close to major harbours has not yet been observed (Bjarne Ålvik and Martin Brinde pers. comm.)

The traditional fishing fleet in Hordaland landed about 617 200 tons of fish in 1996, with a value of about 1.07 billion NOK. The fisheries are conducted by three different fishing fleets of which trawlers and purse seine fish off shore and in more distant waters. The coast fishery is local. Trawlers fish mostly Norway pout (*Trisopterus esmarkii*), sand-eel (*Ammodytes tobianus* and *A. marinus*) and cod (*Gadus morhua*). Purse seine fisheries are concentrated on herring (*Clupea harengus*), mackerel (*Scomber scombrus*) and brisling (*Sprattus sprattus*). Coast fisheries comprise brisling, herring, mackerel, cod, eel (*Anguilla anguilla*), monkfish (*Lophius piscatorius*), saithe (*Pollachius virens*), lobster (*Homarus gammarus*) and crab (*Cancer pagurus*). Introduced pathogenic organisms or species competing for the same resources as the fish stock may be considered as a threat to fisheries. Such things have already happened in the Black Sea since the introduction of the ctenophore (comb jellyfish) *Mnemiopsis leidyi* (GESAMP 1997).

Other potentially harmful organisms are available for distribution along the Norwegian west coast. Thus a national overview of the ballast volume and origin will help to identify the most susceptible areas. On the long term international agreements and implementations of these are necessary in order to prevent further unintentional transfer of organisms via ballast water.



Limulus polyphemus, the horseshoe crab

19.8. Acknowledgements

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20. The ports in the Stenungsund area, west coast of Sweden

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20.1. Environmental profile

20.1.1. General features of the coastal water along the Swedish west coast

The coastal water of the Swedish west coast is affected by two major currents. The brackish surface water originating from the Baltic flows northward via Öresund and the Belts and follows the Swedish west coast. Saline water is carried by the Jutland current from the North Sea passing Skagen and towards the Swedish west coast. The two different water masses are clearly visible in the coastal water. Between these water masses there are a more or less pronounced cline at a depth of 10-20 m. The main currents are only temporarily affected by weather and wind (Björck 1986).

20.1.2. Currents and water exchange in the Askeröfjord

The Askeröfjord is a part of the fjord system running in a south northward direction on the inside of the big islands of Tjörn and Orust (Fig. 1). The Hakefjord is connected with the Skagerrak without a sill and it merges into the Askeröfjord, which turns into the Havstensfjord further north. The Hakefjord and Askeröfjord are comparatively shallow fjords while the northern fjords Havstensfjord, Byfjord and Koljöfjord are deeper. The fjord system emerges in the north at Nötesund (sill depth 10 m). The connection with the open sea and water exchange is high in the Hakefjord and Askeröfjord while the deeper fjords of the north have a poor water exchange and often stagnant water below the halocline.

Figure 1. The big islands of Tjörn and Orust and the surrounding fjords.

The net flow of water in the fjord system is in northward/westward direction. On shorter time scales the semi-diurnal tidal flow, with an amplitude of 15-20 cm, dominates the variability of the sea level and measurements of the current. Meteorological effects have a large influence on the sea level variations over time scales of a few days or longer. The sea level (if the tidal influence is neglected) generally follows the atmospheric pressure changes.

General winds in the area are easterly in November to February, variable in March to May and westerly in June to October. The force of the wind generated current in the

Askeröfjord is approximately 5 m/s. The current is shallow and slow may not influence the water turnover in the entire system, however, during periods of strong westerly winds the sea level within the fjords can rise more than 1 m above the normal (Björck 1986; Liungman *et al.* 1996).

The Askeröfjord and Skagerrak have similar temperatures throughout the water column which indicate a great water exchange with the open sea. In addition, the salinity of the deep water in the Askeröfjord varies over the year, which indicates a high water turnover and thorough vertical mixing.

The coastal water is as well affected by the impact from rivers emerging in the Skagerrak and the Kattegat. A lot of nutrients are carried into the water via rivers. Local fresh water input, particularly from the river Göta älv, may also have a substantial impact on the salinity. The uppermost meters of the water column in the fjord show salinities much lower than the coastal surface waters of the Skagerrak and the Kattegat, which indicate that the river Göta älv influences the fjord system. The peaks of the terrestrial runoff are during spring flood and October and November when precipitation is high. The residual current, which balances the terrestrial runoff, follows the general circulation pattern of the system and is important for transporting substances. Every day the entire fjord system receives 5.4 tons of oxygen consuming biochemical material, whereof the industries are responsible for 0.7 tons and the municipal sewage the remaining. Hence the water coming from the Skagerrak into the fjords bring pollutants from the region of Göteborg via the river Göta älv and into the fjords (Björck 1986).

20.1.3. Hydrographic parameters

The following summary of hydrography at Galterö in the Askeröfjord is based on data acquired from Axelsson & Rydberg 1993; SMHI Oceanografi 1993; Harlén 1996 and reports from the Coastal Water Management programme, performed by a local water protection association (Kustvattenkontrollprogrammet in Swedish) since 1990. This programme monitors hydrographic parameters monthly at a 38 m station (58:06:55 N, 11:48:60 E).

20.1.3.1. Salinity

The halocline is normally located at 10 to 15 m. The salinity of the surface water (0-5 m depth) varies between 20 and 28 PSU with the lowest records in March, coinciding with high terrestrial runoff. The layer between 10 and 20 m, sometimes either below or above the halocline, varies between 24 and 30 PSU. Below the halocline, from 20 to 38 m, the salinity varies between 29 and 34.5 PSU.

20.1.3.2. Temperature

A thermocline is practically non-existing during spring and autumn. During cold winters a thermocline may separate colder surface water from slightly warmer bottom water. In the summer a vague thermocline often occurs at depths around 20 m.

The factor that naturally fluctuates the most in the surface water (0-10 m) is temperature. In February, the surface water temperature can be as low as 0.1˚ C, while at the end of a hot summer the temperature can rise to 22.2˚ C. The lowest bottom water temperature (2.9˚ C) is recorded during winter or early spring and the highest (13.8˚ C) during summer or early autumn.

20.1.3.3. Ice

Ice cover has been studied in the Askeröfjord by SMHI (Swedish Meteorological and Hydrological Institute) for 30 years. Their data show presence of ice cover in 30-40 % of the years. In the ports there might be an ice cover already in the middle of December but mostly not until New Year. Every other year there has been an ice cover present between Stenungsön and the mainland. Generally the ice breaks in the shallow bays and narrow sounds in the middle of March.

20.1.3.4. Oxygen

The bottom water of the Askeröfjord is fairly well oxygenated, generally around 5 ml/l, which is often exceeded. The lowest oxygen concentrations appear in autumn with a recorded minimum of 2.84 ml/l in September and October.

The oxygen saturation in the surface water (0-10 m) is normally 90 - 120 % and in the deeper waters (15-38 m) 50 - 85 %. The lowest degree of saturation, 45 %, was recorded in September and October 1992.

20.1.3.5. Secchi depth

Secchi depth is dependent on the terrestrial runoff and the concentration of phytoplankton. The maximum (9 m) is recorded in January when the phytoplankton biomass and the runoff from land are low. The minimum (2.5 m) is recorded in November when the autumn bloom still persists and the terrestrial runoff is high due to high precipitation.

20.1.3.6. Nutrients

The concentrations of total nitrogen (Tot-N) in the surface water (0-5 m) of the Askeröfjord are quite homogenous with a maximum of 30 µmol/l in winter and a minimum of 17 µmol/l in May. In the deeper water (20-38 m) concentrations are even more homogenous but slightly lower with a maximum of 28 µmol/l in January and a minimum of 15 µmol/l in October.

The concentration of inorganic nitrogen (NO_2-N, NO_3-N, NH_4-N) in the surface water (0-15 m) is tightly coupled to light availability and hence primary production. Generally the concentration is high during winter (maximum: 15 30 µmol/l). It drops sharply in March, coinciding with the spring bloom, and reaches a minimum below 0.130 µmol/l which will from June to October and in November it rises again. The deeper water (20-38 m) show the same trend but it is not as abrupt. During winter the concentration will reach 13 µmol/l and drops down to 4.7 µmol/l in summer.

The concentration of total phosphorus (Tot-P) in the surface water varies seasonally, with the highest concentrations during winter, 1.08 µmol/l, and the lowest, 0.34 µmol/l, in summer. In the surface water (0-5 m) the phosphate (PO_4-P) concentration is generally high in winter, up to 0.7 µmol/l, and decreases after the spring bloom in March to below 0.1 µmol/l which will remain until September. The concentration of the bottom water is more stable but varies likewise with a maximum of 1.01 µmol/l and a minimum of 0.44 µmol/l.

The silica (SiO_3) concentration is generally high in winter in the surface water (0-5 m), up to 20 µmol/l and it drops sharply at the time of the spring bloom in March. Species associated with the spring bloom are mainly silica requiring diatoms. From March onwards the concentrations remain low (0.1 µmol/l) during summer and autumn and rise again in November (10 µmol/l). At 20-38 m, concentrations are more homogenous, with a minimum in April (4.8 µmol/l), and a maximum in September (15.8 µmol/l).

Particulate organic carbon and particulate organic nitrogen (POC and PON) are not investigated at Galterö. The summary below is based on data from Åstol and Stigfjorden (Fig. 1). POC and PON are only measured at two depths (5 and 20 m). The peaks of POC and PON concentrations coincides with the spring and autumn blooms, with slightly higher concentrations in the autumn.

POC: Concentrations are low in January to February at all depths in the water column. Shallow water (5 m) has a slightly higher concentration than deeper (20 m), 8 µmol/l and 6 µmol/l respectively. In March the surface water has high concentrations (up to 40 µmol/l) while the deeper water still has fairly low concentrations (12 µmol/l). These concentrations remain throughout the summer. In September a concentration maximum is reached, with up to 60 µmol/l at the surface and ca 25 µmol/l at 20 m depth. The concentrations drop during the following months.

PON: Concentrations are low in January and February at all depths. Surface water and deeper water (5 and 20 m) have the same concentrations, ca 1 µmol/l. In March the concentration increases the most at the surface, with a maximum of 6 µmol/l and less at 20 m depth, 2.7 µmol/l. The concentrations decrease over summer and peaks in September with a maximum value of 7.1 µmol/l in the surface water and 3.2 µmol/l at 20 m depth.

20.1.3.7. Chlorophyll a

There is a pronounced seasonal variation in chlorophyll a concentration in the coastal water, which is repeated from year to year. The peak of the chlorofyll a concentration is generally between the surface and maximum 10 m depth of the water column, independently of season.

The lowest concentrations are recorded in December to February (< 1 µg chl a/l) due to insufficient light conditions. However, in December late autumn blooms of especially diatoms may give higher concentrations, as well as early spring blooms beginning already at the end of January or the beginning of February, which was the case in 1997. The early spring bloom consists mainly of diatoms and the chlorophyll a concentrations can be as high as 14 µg/l. Spring blooms are often very intense, lasting only a couple of weeks and exhaust the nutrients quickly. In April the nutrient levels are low and consequently the chlorophyll a concentration is low.

In summer nutrients are generally the limiting factor for phytoplankton growth and the chlorophyll a concentrations remain low - typically around 5 µg/l or lower. Whenever higher concentrations are recorded they are mostly coupled to great terrestrial runoff, vertical mixing, or species present with the possibility to break down organic matter in the water column. Usually the autumn bloom will not give rise to such high chlorophyll a concentrations as the spring bloom, but concentrations as high as 15 µg chl a/l, due to dinoflagellate blooms, are recorded in September to October.

20.1.4. Phytoplankton

The following summary of phytoplankton in the Stenungsund area is based on data acquired from Edler 1994, 1995; Kuylenstierna & Karlson 1997; reports from Coastal Water Management Programme performed by a local water protection association since 1990, and monthly reports from Lars Edler, SMHI and Bodil Hernroth (Kristineberg Marine Research centre) to the programme during the period of January 1996 to August 1997. The Coastal Water Management Programme monitors plankton once every month, however, no station in the Askeröfjord is investigated. Locations in the vicinity that are monitored monthly are the Havstensfjord, Åstol, and the Stigfjord (Fig. 1)

A very generalised view of the monthly plankton flora is presented in Appendix A. Below follows a presentation of the plankton composition during a year, based on data from 1992 to 1997. This generalised picture cannot be regarded as a tool for predicting future phytoplankton events in the Askeröfjord or elsewhere, since the entire system is very complex and impossible to predict in detail.

In January the phytoplankton flora is meagre with low individual and species numbers and small flagellates close to the surface dominates. In 1997 the spring bloom started extremely early in the end of January with *Skeletonema costatum* (4 x 105 cells/l) as the dominating species. In February small species dominate, whereas flagellates decrease and diatoms increase at the end of the month. The spring bloom, consisting almost exclusively of diatoms, most often starts in the outer archipelago and reaches the fjords one or two weeks later. In 1997 the spring bloom reached the Stigfjord and Havstensfjord by February. The diatom S. costatum usually starts the spring bloom. In 1997 the concentration of S. costatum was 5 x 106 cells/l.

In the beginning of March the spring bloom normally begins. Diatoms are present in high concentrations. Typical species are *S. costatum*, *Thalassiosira nordenskioldii*, *Leptocylindrus danicus* and *Chaetoceros* spp. It is impossible to predict the exact onset of the spring bloom because of the great annual variation of the actual date. For instance, the spring bloom of 1994 started in the end of March compared to late January in 1997.

The spring bloom is very intense, lasting only a couple of weeks until the nutrients are almost totally deprived. In April the species composition often reflects the situation after a spring bloom consisting of mostly dinoflagellates, small chrysophyceans and the rest of diatoms. Great numbers of small flagellates at the surface (12 x 106/l) have been reported and also the presence of the potentially toxic dinoflagellate *Alexandrium* sp. in small numbers. In May there are more dinoflagellates, small species of Cryptophyceae, other flagellates and less diatoms. In 1997 dinoflagellates (*Scrippsiella*, *Dinophysis*, *Katodinium* and *Alexandrium*) were totally dominating. Mussel harvest was banned in several areas along the west coast due to presence of the toxic dinoflagellate *A. tamarense* in 1997. At Åstol the concentration was 5 000 cells/l. The DST (Diarrhetic Shellfish Toxin) producing species *Dinophysis norvegica* and *D. acuminata* have been reported to occur in May for several years.

Species records and abundance in June vary annually. In 1994 and 1996 the dominating species in the Stigfjord was the diatom *Skeletonema costatum*. Number of cells in 1994 was 5 x 105 /l and for the diatom *Rhizosolenia fragilissima* 8 x 105 cells/l at the surface. In the same year *Dinophysis norvegica* (1000 cells/l) was recorded. In June 1997 *D. norvegica* (25 000 cells/l) was reported from the Havstensfjord. In 1993 a bloom of

Gymnodinium simplex (1 x 105 cells/l) together with high abundance of Cryptophyceae (1 6 x 106 cells/l) was observed.

In July light conditions are optimal but the water column is deprived of nutrients. These conditions favour small species with high surface:volume ratios, which implies that they can utilise the low concentration of nutrients. In several years blooms of the small *Emiliania huxleyi* (Prymnesiophyceae) have been observed in July; generally the species diversity is high. In 1996 the diatoms *S. costatum*, *Proboscia alata* and *Rhizosolenia fragilissima* were the dominating species in the Stigfjord together with the dinoflagellates *Ceratium* spp. and *Dinophysis norvegica*. In 1994 many *C. tripos* (13 500 cells/l) and *Dinophysis* sp. (2000 cells/l) dinoflagellates were observed to coincide with high concentration of the potential AST (Amnesic Shellfish Toxin) producing diatom *Pseudonitzschia pseudodelicatissima* (10-20 000 cells/l). At the same time *Chaetoceros* spp. (> 2 x 105 cells/l) were recorded.

As a rule dinoflagellates dominate in August. Dense blooms of *Prorocentrum micans* (1-1.7 x 105 cells/l) are regularly observed together with other dinoflagellates representing the genera *Ceratium* and *Dinophysis*. In 1994 in the Stigfjord high numbers of dinoflagellates were present in the surface water while the diatoms showed high concentrations in deeper water. Blooms of *Emiliania huxleyi* colouring the water have been observed in August as well as dense blooms of the diatom *Leptocylindrus minimus* (1.2 x 106 cells/l). In 1996 the flora was meagre consisting mainly of Cryptophyceae and other flagellates.

In September there might be a declining number of dinoflagellates if there is no vertical mixing of the water. However, mostly *Prorocentrum micans* will still be present in high numbers together with *Ceratium* species like *C. fusus, C. furca* and *C. tripos*. The DST-producing dinoflagellate *Prorocentrum minimum* was observed in 1995. Other DST-producers commonly found at this time of the year are *Dinophysis norvegica*, *D. acuminata*, *D. acuta* and *D. rotundata*. High numbers of the diatoms *Leptocylindrus minimus*, *Nitzschia longissima* and *S. costatum* have also been observed in September.

October is often characterised by a rich flora consisting of a mix of dinoflagellates and diatoms. The autumn blooms most often refer to dinoflagellates causing red coloration in surface water (down to 6-8 m). In 1996 this phenomenon was caused by *Ceratium furca*, *C. lineatum* and *Noctiluca* in the Stigfjord. Plenty of oxygen is required at the bottom to break down the dead algae after such a dense bloom. In 1994 a bloom of the harmful algae *Gyrodinium aureolum* (32 400 cells l-1) was recorded at the surface and as well as a bloom of the diatom *Leptocylindrus danicus*. The same year a bloom of the toxic species *Prorocentrum minimum* (1.5 x 106 cells/l) in the deep water was recorded in the Havstensfjord, simultaneously with a diatom bloom of *Leptocylindrus minimus, Nitzschia longissima* and *S. costatum* in the surface water.

In November there is still enough light and nutrients in the water to induce substantial phytoplankton growth of mainly dinoflagellates. Species of the genus *Polykrikos* are often abundant at this time of the year together with *Dinophysis* spp., *Gymnodinium* spp., *Prorocentrum micans*, *Protoperidinium divergens*, *Katodinium rotundatum* and *Ceratium* spp. High abundance of diatoms are not unusual. The potential AST producer *Pseudonitzschia pseudodelicatissima* has been observed in high numbers in the surface water several years.

Usually the light is insufficient for algal growth in December. The flora is comparatively meagre consisting of a few dinoflagellates and small flagellates. However, in 1994 an autumn bloom of diatoms with a remarkably diverse flora consisting of *S. costatum* (6.6 x 105 cells/l), *Leptocylindrus danicus* (2 x 105 cells/l), *Pseudonitzschia pseudodelicatissima* (2 x 105 cells/l) and *P. seriata*, was recorded.

20.1.4.1. Dinoflagellate cysts

Many of the dinoflagellates of the Scandinavian waters form resting spores (cysts) as a part of their life cycle through sexual fusion of two gametes. The newly formed cyst loses its mobility, slowly sinks through the water column and eventually reaches the bottom. The dinoflagellate cysts in the sediment hatch if conditions are favourable, and the cysts may act as “seeds” for initiating dinoflagellate blooms (Dale 1983). The cysts are dormant and have a very limited exchange with their environment. Dinoflagellate cysts are transported via ships’ ballast water and survive the transport due to their inactive physiological state (Hallegraeff & Bolch 1992).

The concentration of dinoflagellate cysts in the Askeröfjord is high (18 000-97 000 cysts per gram dry weight sediment). However, there is a trend along the coast that locations in the inner archipelago have higher concentrations of cysts in the sediment. In the Askeröfjord the cyst flora is dominated by the bloom forming but non-toxic species *Lingoludinium polyedrum* (50 % of total count). It is a common feature for the entire coast line that *L. polyedrum* dominates in eutrophicated sites in the inner archipelago. Cysts of the potential PST-producing (Paralytic Shellfish Toxin) species *Alexandrium tamarense*, *A. minutum* and *Gymnodinium catenatum* are present in low abundance in all samples taken from the Stenungsund area (Persson & Godhe 1997).

20.1.4.2. Harmful phytoplankton species

Some species of algae are considered harmful to humans or human activities because they can produce toxins or mucus or they have sharp spines that might cause damage to fish gills when the algae are present in high concentrations (Hallegraeff 1995). The harmful species recorded from the Stenungsund area are:

PST producing species *Alexandrium minutum*, *A. tamarense*, *Gymnodinium catenatum*

DST-producing species *Dinophysis norvegica* , *D. rotundata*, *D. acuta*, *D. acuminata*, *Prorocentrum minimum*

AST-producing species *Pseudonitschia delicatissima*, *P. pseudodelicatissima*, *P.seriata*, *P. torgidula* and *P. pungens*. Only *P. seriata* and *P. pseudodelicatissima* from Scandinavian waters are proven to be toxic (Lundholm *et al.* 1994; 1997), the other species that are recorded toxic elsewhere, are still not proven to be toxic in Nordic waters.

Chrysochromulina spp.

Prymnesium parvum

Gyrodinium aureolum

Chaetoceros spp.

Dictyocha speculum

20.1.4.3. Okadaic acid in mussels

The Coastal Water Management Programme have been analysing “wild” blue mussels (*Mytilus edulis*) at ten positions along the coast of Göteborg and Bohuslän once a week since 1990. In addition, the cultivated mussels are analysed before marketing. Marketing of blue mussels is stopped whenever concentrations of okadaic acid are higher than 60 µg per 100 g mussel tissue. The risk of elevated concentration of DST (Diarrhetic Shellfish Toxins) is highest from September to December (Edebo 1994-1997).

In April and May 1997 the first Swedish record of PST in blue mussels above the recommended limit for human ingestion occurred (Tångesund, 800 MU per 100 g mussel tissue and Tjärnö, 589 MU). The causative organisms belong to the PST producing genus of *Alexandrium*.

20.1.5. Macroalgae

The distribution of macroalgae and long term changes of the flora has been studied within the programme of a local water protection association at Galterö in the Askeröfjord since 1992. A hard bottom transect is followed once a year down to a depth of 6.5 m. The same transect was used between 1979 and 1986 within the MUST (Miljöutredningen för Stenungsund) programme conducted by the Swedish EPA. This summary is based on reports and data from Näslund 1986; 1992; 1993 and 1995.

In 1979-1985 the flora of macroalgae was investigated at four different transects in the Stenungsund area. The station mentioned above (Ste 3), one transect south of the industrial area of Stenungsund (Ste 1), one transect within the harbour area (Ste 2) and one transect (Ste 4) on the west side of the Askeröfjord. Typical of all the transects studied was a disturbed environment with heavy sedimentation and decreasing species diversity, whereas vegetation underneath the surface appeared normal at all four stations. In 1985 crustaceous red algae had decreased and filamentous green algae (*Cladophora flexuosa*) had increased, when comparing to monitoring from the earlier years of the period 1979-1984. A powerful settling of Mytilus edulis was observed and many algae seemed to have lost their natural protection against fouling which means that filtering fauna (*Ciona intestinalis*) had found new niches on the algae. Exceptions from these trends could be seen only at Ste 4, the transect off the island of Stora Askerö. In this site the algae still had protection against fouling organisms and the species composition had been homogenous over the years. There was an insignificant influence of strong currents on sedimentation and settling of blue mussels. Filamentous green algae, like *C. flexuosa*, had increased its coverage but was not dominating, as it was at the other stations.

South of Stenungsund, at Ste 1, the flora appeared healthy in 1979 but a degeneration has been observed since 1980. Great differences between 1983 and 1985 are reported with a pronounced decrease of species diversity and a total domination of *C. flexuosa*. The transect within the harbour area, Ste 2, was in 1979 already disturbed, it has been reported to worsen with time, and in 1985 the bottom area appeared dead. Sulphur bacteria and substantial sedimentation were observed that year. Earlier investigations from 1983 showed that the red algae *Ceramium rubrum* grows down to 7 m depth, while two years later in 1985 the distribution was reduced to 3.5 m depth. The transect at Galterö, Ste 3, was somewhat healthier during this period compared to the transect from the harbour area.

In 1992 only one transect (Ste 3) was investigated at Galterö. The overall impression of the entire transect was a disturbed environment dominated by filamentous brown algae and it was exposed to substantial sedimentation. The vegetation was sparse deeper than 3 m and *Ciona intestinalis* was dominating. The transects in the harbour area (Ste 2) and the transect off the island of the Stora Askerö were reinvestigated in 1993 together with the transect at Galterö. The three stations in the Askeröfjord had the lowest number of species and individuals compared to all the transects studied in the monitoring programme of the entire coast of Bohuslän. The limit of vegetation was at 3 m depth and there was a substantial reduction in flora coverage when compared to 1979. Even the abundance of filamentous brown and green algae had decreased since 1992. For distribution and species at Galterö in 1993 and 1995 see Appendix B.

In the harbour area (Ste 2), the flora is exposed to substantial sedimentation and turbulent currents from the tanker traffic. The number of individuals has decreased since 1986. Species diversity and coverage was similar to observations at Galterö (Appendix B). *Fucus vesiculosus* was present in a moderate coverage down to 1.5 m, while *Furcellaria lumbricalis* was absent at Ste 2.

In 1993 the transect at Stora Askerö (Ste 4) was again the “healthiest” transect of the three. However, sedimentation is substantial and a degenerated flora was encountered already in 1986. This investigation showed a further degeneration, consisting of an increasing number of filamentous annuals together with a flora heavily overgrown by epifauna at depths greater than 2 m. The species diversity and coverage was similar to Galterö (Appendix B) but in somewhat better condition. *Laminaria saccharina*, *C. rubrum*, *Fucus serratus*, *F. lumbricales*, *C. flexuosa* and Ectocarpales were growing deeper at Ste 4. The brown algae *Halidrys siliquosa* was observed at this transect growing at a depth of 2 to 3 m, with a coverage less than 20 %.

In 1995 the transect at Galterö was the only one studied. The algae were in minority and the bottom substrate was dominated by filtering animals. The recorded poor species diversity since 1992 was still prevalent. Vegetation coverage deeper than 2 m was sparse and consisted mainly of encrusted red algae. Filtering sessile animals, such as blue mussels and sea squirts, had increased in number and the algae seemed to play a less dominating role. Many representatives of red and brown algae showed abnormalities or the specimens were very small. Very few individuals of any species were observed beyond 4 m depth. Dominating species and relative coverage are presented in Appendix B.

20.1.6. Soft bottom fauna

Soft bottom fauna at Galterö in the Askeröfjord has been studied annually since 1991 (Tunberg 1996; Tunberg & Hammar 1992). Analyses comparing data from the years 1991 to 1996, show fluctuations in respect of species diversity and biomass. The data from 1993 differs most from the others while the period of 1991-92 and 1994-96 is more similar. The records from 1993 show low species diversity, number of individuals and biomass per square unit. It is speculated whether 1993 was a “bad” year, and if the fauna was slowly recovering to its initial state during 1994 to 1996, hence the similarities between the earlier and the later periods (Tunberg 1996).

In 1991 the number of individuals was high (6 200 ind/m^2), the biomass was comparatively high (180 g/m^2) and the number of species (75 recorded species) was the highest of the five stations investigated along the entire coast of the county. Polychaetes, molluscs and crustaceans, in that order, were the dominating groups in respect of abundance. The location was considered to harbour a rich and healthy bottom fauna.

From 1991 to 1993 there was a pronounced decrease in the number of individuals per square unit (from 6 200 to 3 900 ind/m^2) within the crustaceans, molluscs and polychaetes groups while echinoderms had increased somewhat. Total biomass per square unit had not decreased, whereas the biomass of crustaceans had decreased significantly and the biomass of echinoderms had increased. Species diversity had declined from 75 to 51 species.

In 1994 all groups had increased in abundance, except echinoderms, which gave an increase of total number of individuals (6 200 ind/m^2). The total biomass per square unit had increased to the same level as in 1991 (200 g/m^2). It is considered that no serious impact from outer effects could have caused the fluctuations of diversity and total biomass from 1991 to 1994 (Tunberg 1996).

The total abundance had decreased in 1995 (4 800 ind/m^2) due to the decrease of molluscs and crustaceans. A decline of total biomass (150 g/m^2) was recorded mainly as an effect of decreased biomass of echinoderms. The species diversity had increased slightly.

An increase in abundance of polychaetes and molluscs in 1996 had caused the number of individuals to increase (5 900 ind/m^2). Total biomass had increased (200 g/m^2) due to increase of biomass of polychaetes and molluscs and the number of species had increased to 90 species.

In Appendix C a list of dominating taxa and their respective mean value of individuals per square unit of the period 1994-96 is presented.

20.1.7. Hard bottom fauna

At Djurnäs udde hard bottom fauna has been investigated along five transects annually at spring time in 1994-96 (Adolfsson & Tunberg 1994; 1996; 1997). The studies cover hard bottom communities from 0 to 20 m depth (Fig. 1).

The number of recorded taxa is fairly constant over the years, ranging from 29 to 31. The fauna coverage is comparatively high at all depths, up to 60 % at 6 m depth. From the surface to 1 m depth the blue mussel *Mytilus edulis* dominates. The abundance of *Mytilus* in this zone has varied much over the year, possibly due to cold winters and ice coverage. *Mytilus* has been recorded to as deep as 4 m. Common starfish *Asterias rubens* has increased since 1994. Since it is a predator of blue mussels it could be part of the explanation for the fluctuating abundance of *M. edulis*. Investigations from earlier years showed a much higher abundance of serpulids. The decline of serpulids could have been caused by increased sedimentation or poor water circulation. The trends of 1994-96 show an increase in coverage of anthozoa, with *Metridium senile* as the dominating species. At 12 m depth the coverage of *M. senile* is as high as 10 %. The coverage of ascidiaceans, mainly *Ciona intestinalis*, has fluctuated greatly from year to year. The records from 1994 show a coverage of approximately 70 % of the substrate of *C. intestinalis* at 4-10 m depth. In 1995 the population number had diminished greatly and in 1996 it was increasing again, but not to the same levels as in 1994 (Adolfsson & Tunberg 1994; 1996; 1997).

In Appendix D a table of recorded taxa is presented. This table includes a mean relative coverage of all species at different depths from five transects at Djurnäs udde 1994-96.

20.1.8. Mobile epifauna

Mobile epifauna has been investigated at Galterö twice a year since 1994 and once a year, in autumn, between 1991 and 1993 by a local water protection association. The area has previously been investigated from 1979 to 1985 in respect of mobile epifauna by MUST (Miljöutredningen för Stenungsund). Sampling is conducted in shallow areas with or without vegetation at a depth of 0 to 0.7 m. The following summary is based on data acquired from Lagenfeldt 1986 and Thörnqvist 1996.

The observations of mobile epifauna in 1991 displayed a high number of species (18) and high biomass (22.6 g/m^2). In 1994 the number of species was markedly reduced consisting of only five species and the biomass was also reduced to 6.6 g/m^2. These great fluctuations could be an effect of decreasing vegetation cover (from 30 % in 1991 to 0 % in 1995). The percentage cover in 1991 and 1992 was 20 to 40 % consisting mainly of *Mytilus edulis* and *Zostera marina*. In 1995 the bottom was bare, 80 to 100 %, with some *Zostera* in the summer and some *Mytilus* in the autumn. A species list including species- and total biomass from the years 1985, 1991, 1992 and 1995 is presented in Appendix E.

Within the MUST programme, mobile epifauna were studied at three different localities. At Grönvik two different bottom substrates, a bare bottom and a *Zostera* habitat, were studied in summer and autumn of 1979 and in autumn in 1985. Three different habitats were studied in the Jordhammarsbukt. Two bare bottom habitats and a *Zostera* habitat were investigated during summer and autumn of 1985. At Nönäs south of the Tjörnbro (Fig. 2), a disturbed area next to a yacht marina and close to the outlet of street runoff from Stenungsund centre, one bare bottom and one *Zostera* habitats were investigated in summer and autumn of 1979 and 1985, while another bare bottom habitat was studied in summer and autumn of 1985.

In general, the bare bottom habitats had lower biomass in summer compared to the biomass in autumn. The species number did not differ seasonally, but between different localities there was an apparent difference. At Grönvik the maximum number of species found was 13, in Jordhammar 10 and in Nönäs only 6 species.

The *Zostera* habitat showed the same trends with lower faunal biomass during summer compared to autumn observations. At Nönäs no seasonal difference in species number was observed while in Grönvik the species number was much lower during summer. Key species of *Zostera* habitats, such as *Gobius niger* and *Palaemon adspersus*, were missing in the *Zostera* habitat of Jordhammar and the common species *Palaemon elegans* were not found in any of the *Zostera* habitats. The *Zostera* habitat of Jordhammar had a clearly lower biomass and number of species than Grönvik, and than the average *Zostera* habitat of Bohuslän. *Fucus serratus* was present in the *Zostera* habitat of Jordhammar and Nönäs in 1979 but had disappeared in 1985.

Important species such as green crab *Carcinus maenas*, plaice *Pleuronectes platessa*, *Palaemon elegans* and black goby *Gobius niger* were missing at one of the bare bottom habitats in Jordhammar. A species list including species and total biomass of one of the bare bottom habitats in Jordhammar is presented in Appendix E.

20.1.9. Fish

From 1962 to 1985 the most common species of commercial valuable fish in the Askeröfjord were plaice *Pleuronectes platessa*, dab *P. limada*, flounder *Platichtys flesus* and cod *Gadhus morhua*. In general, *P. platessa* and *P. limada* dominates the catches in 1969-70, and in 1980-84 *P. flesus* dominates the catches. During 1985 the total catch was reduced. However, since 1979 the catches of *P. platessa* have reduced, which is probably due to the disturbed environment. In contrast, *P. limada* and *P. flesus* show a positive trend (Jacobsson 1986).

20.1.10. Long term changes, parasites and diseases in fish

In order to study long term morphological and physiological changes of fish, the spread of diseases and parasites in the flounder *Platichthys flesus* is examined annually at four different stations along the coast of Göteborg and Bohuslän, of which Galterö is one. The methods and analyses used are according to ICES (International Council for the Exploration of the Sea) standard.

P. flesus lives in tight contact with the bottom substrate, is considered stationary and hence a species that will reflect external fluctuations in the region. Approximately 300 specimens of *P. flesus* are caught and examined from the Hake- and Askeröfjord every year in order to get an estimation of local variation. The following summary is based on Lagenfeldt & Westerberg 1991; 1993; 1994, Lagenfeldt 1996; 1997.

Parasites and/or parasite induced wounds analysed are *Glugea stephani*, *Lymfocystis*, ulcerative dermatitis, *Ichtyphonus*, *Acantochdria cornuta* and *Lepeophtherius pectoralis*.

Glugea stephani is an unicellular microsporan intestine parasite. An outbreak of *G. stephani* was recorded in the years 1991-92 when more than 10 % of the population were infected by the parasite. In 1996 less than 2 % of the population were infected.

Lymfocystis is caused by viruses that cause unicellular cysts to form. The disease does not seem to affect the fishes' well-being to a wider extent. An outbreak was recorded in 1992-93 when 20 % of the population were infected. This was the highest record along the coast. After the outbreak in 1993 it has stabilised and today approximately 10 % of the population are infected.

Ulcerative dermatitis appears as open round wounds caused by viruses or bacteria. A clear correlation with pollutant from cellulose industry and presence of ulcerative dermatitis has been shown. Galterö had high records during the years of 1992-93 when the other stations had low values. The presence of this disease appears to fluctuate with time and space.

Ichtyphonus is a parasitic fungoid growth. Records show the same trends along the entire coast, low percentage of infection in 1992 and high (9-12 %) during 1993, followed by a decline.

Lepeophtherius pectoralis and *Acantochdria cornuta* are the most frequent fish parasites examined. *L. pectoralis* is an exoparasitic crustacean, which can cause damages to the skin. It was present in 70-90 % of the fishes examined. *A. cornuta* is a parasite on the fish gills, which can cause tissue damages and necrosis of the gills. *A. cornuta* appeared very frequently, 80-100 % of the population was infected.

Morphological injuries such as lordosis and scoliosis, i.e. bending of the spine, have only been observed in some few specimens over the years in the entire examined area. Pigmentation anomalies are considered normal in the region, around 30 % of the population have abnormal pigmentation.

Fin decay might be caused by mechanical injuries that starts an infection of bacteria or physiological alterations of the blood circulation in the fins. From 1992 to 1993, the caught specimens with fin decay increased from 0.7 to 6.5 %. Other mechanical wounds investigated during the examination of the fishes, caused by nets, predators etc. have the highest percentage at with 7 % of the population affected Galterö in 1991.

20.2. Harbour traffic profile

The environment of the Stenungsund area is affected by the traffic of ships through the waterway from Marstrand to Uddevalla, which is the only route used by ships arriving in Stenungsund and the major route used by ships arriving in Uddevalla. Therefore, when considering the risk of introducing NIS into the area of Stenungsund via ship's ballast water or as fouling organisms of ships' hull, it is necessary to take into consideration not only the traffic to the ports of Stenungsund but also the traffic to and from Uddevalla. The waterway allows a maximum depth of 13 m for ships arriving in Stenungsund and 10 m for ships arriving in Uddevalla. Normally the waterway is not used by ships greater than 30 000 tons. However Nanny, a huge ship of 485 000 tons built at the ship yard at Uddevalla during the 1970's, sailed through the waterway (Granhed & Johansson 1982). Uddevalla is also reached by the waterway north of the island Orust by ships that weigh less than 3 000 tons, but this waterway is not used by the extra-European traffic which will be considered below.

20.2.1. Ports of the area

Data of arriving and departuring ships from Stenungsund and Uddevalla have been acquired from the Central Department of Statistics (Statistiska Central Byrån - SCB), Shipping Section. The data set is from the first six months of 1996. Communication with respective commanding chiefs of the harbours reveals that the traffic is more or less homogenous from year to year.

In Stenungsund there are four major private ports owned by industries. On average 1 000 ships arrive annually, carrying 3.5 million tons of goods. The most important Swedish ports in handling petrochemical products are situated in Stenungsund.

20.2.1.1. Vattenfall

Vattenfall owns the biggest port of Stenungsund with approximately 350 calls annually. During the period of January to June in 1996 there were eight registered extra-European calls, from USA, Mexico, Venezuela, Libya and Taiwan. All were unloading except the ship arriving from Taiwan. Of the port calls 92 % were ships arriving from and departing for NW European ports, i.e. Belgium, Germany, Denmark, Great Britain, Norway, other Swedish harbours, the Netherlands or Finland, while 3.4 % of the ships were arriving from or departing to south European ports, i.e. Spain, Portugal or France (Appendix F).

The most common ship type was tanker (90 %) and the rest were chemical sanitation ships, analogous to bulk carriers. Major import goods are oil and oil products for power plants owned by Vattenfall and to some extent chemicals for Borealis. The exported goods are oil products, coal and non-coal based chemicals, manufactured by the Borealis group of industries.

20.2.1.2. Borealis

Havden is the port owned by Borealis and there are approximately 300 calls every year. Borealis imports large quantities of oil products such as naphtha, propane and butane. Of the port calls 88 % are tankers carrying these products, while 12 % of the calls concern export of propane gas. During the period of January to June 1996 there was one extra-European call from Saudi Arabia, a tanker delivering oil products. Of the port calls 90 % were ships arriving from and departing for NW European ports (Belgium, Germany, Denmark, Great Britain, Norway, other Swedish harbours, the Netherlands or Finland), 5 % of the calls were ships arriving from or departing to southern European harbours and 3 % to ports in the Baltic countries. Of the calls registered 98 % were tankers and 2 % were bulk carriers (Appendix G).

20.2.1.3. Norsk Hydro Plast AB

There are approximately 150 calls at the port owned by Norsk Hydro Plast AB every year. During the period January to June 1996 there was one extra-European arrival, a tanker with last port of call in India loading PVC in Hydro’s harbour. The traffic to western European countries (Belgium, Germany, Denmark, Great Britain, Norway, other Swedish harbours, the Netherlands or Finland) was dominating (93 %). Connections with the Baltic countries or Poland made up 5 % of the traffic. Of the registered calls 33 % were bulk carriers and 67 % were tankers (Appendix H).

Roughly 50 % of the calls constitutes of import and 50 % export. Imported goods are salt from Holland, Denmark and Great Britain, and vinyl chloride from Norway. The exported goods are mainly lye to other Swedish ports and the Baltic states and in addition export of vinyl tiles to various European countries.

20.2.1.4. Ballast Väst

The smallest harbour of Stenungsund is situated at Talludden and owned by Ballast Väst. The traffic mainly constitutes of export of macadam (92 %) and as a rule there is no import of goods. Occasionally there might be incidents when there is a mutual use of ships (e.g. salt is delivered to the harbour of Hydro and the same ship goes back loaded with macadam). During the first six months of 1996 there were 24 calls to Talludden whereof 96 % were bulk carriers and 4 % tankers. No extra-European arrivals were registered and 75 % of the traffic were in connection with Germany or Denmark. Seventeen percent of the traffic was arriving or departing for other Swedish harbours, Norway, the Netherlands or Great Britain, while 8 % of the traffic was to the Baltic Russia or Poland (Appendix I).

20.2.1.5. Uddevalla

Uddevalla is one of Sweden’s major cargo handling ports specialised in handling bulk cargoes and forest products, as well as general cargo shipped in either semi-container or ro-ro vessels. Products exported from Uddevalla are paper, pulp and forest products, fertilisers, non-ferrous ore, grain and macadam. The major imported goods are oil products, ore, grain and foodstuff, fruits, paper and cardboard, metals, construction materials, fertilisers and macadam.

During the first six months of 1996, 368 arrivals were reported from Uddevalla of which 21 % had their last port of call outside Europe. These extra-European arrivals were all bulk carriers or ro-ro carrier.

20.2.2. Ballast water

20.2.2.1. The general ballasting cycle

The actual amount of ballast water aboard a vessel on its way to an export facility depends on the type and size of the ship. It also varies according to weather and the length of the voyage. A ballast tonnage at 25 % is considered the norm, 20 % for short trips and good weather, 30 % for heavy weather. Empty ships trading over sea ports and encountering heavy weather en route, have in most cases plenty of opportunities to discharge their extra ballast prior to reaching coastal water near the receiving port (Hayes & Hilliard 1996).

The actual volume of ballast water of foreign origin discharged inside the port or in the waterway is also governed by the amount of cargo already on board, the success of deep water reballasting programme recommended by international authorities (ICES 1994), the need to keep the propeller of the ship sufficiently immersed, the need to minimise the windage when passing narrow or shallow channels at slow speed and the “air draft” limitation that can apply when berthing at the port. Preliminary discharge of ballast water may be started in the waterway on the way to the berthing area. Typically 5- 20 % of the ballast water can be discharged without loosing manoeuvrability. The remainder of the ballast water is discharged alongside the berth in close co-ordination with cargo loading to avoid placing dangerous stress on the ships’ hull (Hayes & Hilliard 1996). In some instances ships might take in ballast water while loading in order to keep the vessel in balance.

20.2.2.2. Ballast water discharge in the Stenungsund area

There is no information available in any of the ports neither of Stenungsund nor in the port of Uddevalla on how much ballast water is discharged in the area and where the ballast water is discharged. Since July 1997, the Swedish EPA has distributed questionnaires on ballast water handling for ships calling Swedish ports; this is the first investigation of ballast water discharge in Swedish waters.

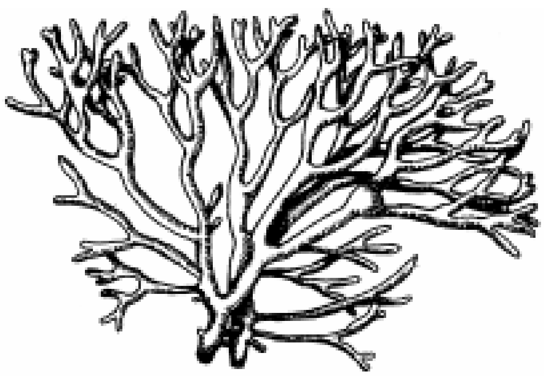
None of the ports in the area have any assigned plant for handling ballast water. According to port authorities there has not been any need for such permanent construction. If there were any reason to take precautions due to polluted ballast water, i.e. containing oil, a truck with mud suction capacity would be called for (pers. comm. Morgan Lexberg, Commanding chief, Port of Uddevalla).

Staff of the ports report that normally the ships empty their ballast while loading inside the harbour. One exception is Talludden, the smallest harbour of Stenungsund exporting fair quantities of macadam. The installation for loading macadam onto the ships has a height of 8 m, which means that the ships do not need to be lower. In order to acquire the correct height the ships may need to discharge a greater volume of the ballast just outside Stenungsund.

Calculation of ballast water volumes in the area of Stenungsund focuses on ships arriving from extra-European ports (see also 3.4). Ships arriving from outside Europe intending to load in a Scandinavian port will have ballasted the major part of their water in the last port of call. However, there could be a rest of ballast water ballasted elsewhere before reaching the last port of call, which still is not discharged. This means that the ships recorded as intra-European traffic in Appendix F-I might as well carry extra-European ballast water travelling on an intra-European route. Furthermore, while ballasting in shallow water it is inevitable that sediment mixed with various resting spores and benthic organisms, comes into the ballast water tank together with the water. The sediment will sink to the bottom of the tank and stay there until it is cleaned out manually. Calculations of extra-European ballast water discharged in the Stenungsund area are presented below. Due to lack of information and appropriate data on the exact origin of the carried ballast water only the vessels with last port of call outside Europe will be considered.

The ships carrying import products to the receiving ports have no need to release ballast water within the port limits and will not be treated below when estimating the amount of foreign ballast water discharged in the area.

German ports and related traffic have been investigated in a study from 1992 to 1996 (Gollash *et al.* in prep.). A mean maximum ballast water capacity for different types of ships has been estimated from a large data set collected during this period. Different ship types have different areas for holding ballast water and the ballast water capacity is expressed as a percentage of the gross tonnage (GT) of the ship. This percentage varies between different types of ships. Gross tonnage (GT) of each and every exporting ship has been acquired from the Swedish Central Department of Statistics. The maximum ballast water capacity (GT) of each ship has been calculated according to Gollash *et al.* (in prep.) and converted into tons of ballast water where 1 GT equals 2.8 tons of water. It is assumed that the exporting vessels arrive to the loading berth in ballast, carrying 80-95 % of their ballast water capacity. The remaining 5-20 % of ballast water has been discharged while going through the waterway leading to the port of anchor, and is of interest when investigating the entire area.



Codium fragile, a green alga

In Appendix J, the two exporting vessels with last port of call outside Europe arriving in Stenungsund between January to June 1996 are listed. Their total ballast water capacity is, according to figures mentioned above, 6 625 tons and it is discharged mainly inside the port. In Appendix K, the 62 exporting vessels are listed with last port of call outside Europe arriving in Uddevalla between January and June 1996. Their total ballast water capacity is, according to figures mentioned above, 307 400 tons. Most of this water will be discharged in the port of Uddevalla while loading but 5-20 % will be deballasted while sailing through the waterway from Marstrand to Uddevalla. This means that a minimum of 15 400 tons and a maximum of 61 500 of ballast water of extra-European origin is discharged in the waterway.

20.3. Risk profile

20.3.1 Potential organisms to become introduced into the Stenungsund area

Organisms that have the potential to be introduced to the Stenungsund area follows. The ones that are mentioned only by their name are discussed further in the main report (Chapter 15.3).

Macroalgae. *Caulerpa taxifolia* is a macrophyte of subtropical origin and was introduced to the Mediterranean in 1984, where it is today considered a pest spreading at an enormous rate (Carlton 1996b). There is a substantial traffic between the area of Stenungsund and the Mediterranean (Appendix K), and a risk that the weed could come to Scandinavia via ballast water or as fouling organism. However, it is doubtful whether the species could become established since the temperature of the Kattegat and Skagerrak is too low. Of algal species introduced to Europe with a larger potential to establish on the Swedish west coast, the most likely candidate might be the red algae *Asparagopsis armata* (the terasporophytic stage earlier named *Falkenbergia*). After arriving in Ireland in 1939 and in UK in the late 1940's, it has been recorded in Shetland since 1973 (Eno *et al.* 1997). Other plausible candidates are two small species of the red algal genus *Antithamionella* (both capable of spreading through fragmentation and occurring in Scotland) and the red algae *Polysiphonia harveyi* occurring in Norway and Scotland.

Unnidaria pinnatifida - Japanese kelp.

Phytoplankton. Several of the toxic cysts forming species are known from the Skagerrak, however, some species of the PST producing genera *Alexandrium* and *Pyrodinium* have not been encountered in Swedish water yet. In fact, relatively few cysts of toxic species found in Swedish water (Persson & Godhe 1997) and blooms of these species are a recent phenomenon (see Environmental profile, section 4). Most probably these species will be unintentionally imported via ships' ballast water, and this may increase the frequency of toxic blooms in the future.

Pfiesteria piscida

Cnidaria. *Maeotias inexspectata,* the Black Sea jellyfish, invaded San Francisco Bay in late 1980's (Carlton 1995) and might turn up elsewhere. *Clavopsella navis,* is a small brackish water hydrozoan that has been found in several port areas including a British lagoon, the Kiel canal and Cape Town (Eno *et al.* 1997) probably spread by ships' hulls. However, it is not known to be an invasive species.

Haliplanella lineata

Mnemiopsis leidyi - combjelly

Polychaeta. *Marenzelleria viridis,* is a polychaete worm that has not yet been present on the Swedish west coast, although closely related species are (Hansson 1993). Fjords adjacent to the Stenungsund area, the Havstensfjord, Koljöfjord, Byfjord, have a low oxygen content in the bottom water. It is a result of poor water exchange with the open sea of the Skagerrak. *M. viridis* could be a successful invader into these fjords since the species is known to be capable of withstanding oxygen stress in the Baltic. *Ficopomatus enigmatus,* is a tube-building, stress tolerant species that prefers brackish water and needs warm water to reproduce. It can, however, generate large populations that are easily transported by the tubes on ships' hulls (Eno *et al.* 1997). Although not being well adapted to our colder climate, it might thrive in cooling outlets as a major fouling organism.

Sabella spallanzanii

Mollusca. *Dreissena polymorpha*, the zebra mussel, has a wide salinity tolerance, however, it could not survive in a true marine habitat and it is doubtful whether it could survive in an estuary with salinities as high as recorded from the Askeröfjord. This could also be true for other species of *Dreissena* that have been introduced to the Great lakes, *D. bugensis* (Jansson 1994).

Potamocorbula amurensis - Chinese clam

Crustacea. *Cercopagis pengoi,* the spiny waterflea, prefers salinities around 10 PSU, hence it is doubtful whether it would be a successful invader of the Swedish west coast (pers. comm. Dr Vadim Panov, University of St. Petersburg).

Hemigraspus sangui - Japanese shore crab

Ehinodermata. *Asterias amurensis* - North Pacific starfish

Ascidea. *Styela clava*, the Pacific leathery sea squirt, is invading European waters. In 1950's it was first seen south of the British Isles, and it was believed to have been fouling the hulls of the warships returning from the Korean War (Eno *et al.* 1997). It occurs in Scotland, The Netherlands and Denmark, and is very likely to be introduced to the Swedish west coast as fouling as it is tolerant for salinity and temperature fluctuations.

Fish. *Neogobius melanostomus,* the round goby, is not registered on the west coast, but it might well become introduced, probably mainly in freshwater influenced areas.

Parasites and viruses

20.3.2 Potential organisms being exported from the Stenungsund area

Macroalgae. The japweed *Sargassum muticum* has not yet been recorded from the Stenungsund area, east of the big islands Tjörn and Orust. It is not clear why it is not present in these fjords, while it is established along the entire west coast from the county of Halland to the Norwegian border. Neither is it known whether the species pose a threat towards the Baltic (Karlsson 1996). *S. muticum* has successfully spread along the west coast of North America, but there are no records from the east coast. *S. muticum* fouling on ships' hulls is liable to spread further from the Swedish west coast into new areas.

Phytoplankton. Several harmful algae are recorded from the west coast of Sweden, which could be liable to be exported to new areas via ships' ballast water. The cyst forming and potentially PST producing species, *Alexandrium minutum*, *A. tamarense* and *Gymnodinium catenatum*, are all found in the sediment of the Stenungsund area

(Persson & Godhe 1997). These cysts might be taken into the ballast water tanks while ballasting in the shallow ports and transported to new areas. Other harmful algae that could be exported are *Prorocentrum lima,* a benthic DST producing dinoflagellate. It lives as an epiphyte on macroalgae and fouling macroalgae of ships' hull and could serve as a vector for the spread of *P. lima*. *Gyrodinium aureolum*, known as a fish killer, is also present along the Swedish west coast and might become established elsewhere via ships' traffic. The species of the potential AST producing genus *Pseudonitzschia* could also spread further from the Swedish west coast. Several of the harmful microalgae present on the Swedish west coast are not recorded from the Baltic. Some species are true marine species and could not survive in the brackish water of the Baltic, whereas others might survive and become established. The traffic from the ports of Stenungsund to ports in the Baltic Sea area are extensive and there are several opportunities for microalgae to be transported into new areas (Appendix F-I).

Crustacea. *Balanus improvisus*, a barnacle believed to be native to the east coast of North America, has to the present spread all over the world including the Skagerrak, the Kattegat and the Baltic (Leppäkoski 1991). *Carcinus maenas*, the green shore crab, is native to the North Atlantic region and has recently appeared to be an extremely successful invader. During the last decades it has become established in the NE Pacific, in Australia and in South Africa (Grozholz & Ruiz 1996) and is considered a pest in many areas. *Eriocheir sinensis*, the Chinese mitten crab, was brought in the 1930's to Europe from SE Asia via ballast water (Leppäkoski 1984). Since it is already known to be a successful invader it might spread further from the Swedish west coast.

Echinodermata. A close relative of the North Pacific starfish mentioned above, *Asterias rubens*, is a common member of the hard bottom communities of the Swedish west coast. *A. rubens* potentiality as a successful invading species is not known but since it is a dominating member of the native community it might be considered as a hot spot organism.

Tunicata. *Ascidiella aspersa* is a common sea squirt populating the Swedish west coast. It has been a successful invader of the North American east coast where it has spread from Massachusetts to Connecticut since it was introduced in the mid 1980's. The vectors for spreading *A. aspersa* from Europe to America were either larvae being transported in ships' ballast water tanks or adults fouling ships' hull (Carlton 1993).

20.3.3. Stenungsund and Uddevalla as "hot spot areas"

In January to June 1996, the exporting vessels arriving in Stenungsund with last port of call outside Europe arrived from India and Taiwan (Appendix J). As mentioned above, for a successful introduction there should be compatibility between the donor and the recipient areas in respect of salinity and temperature. Since these ships arrive from lower latitudes the species carried in their ballast water tanks may not survive the cold climate of the north and hence do not pose a threat. In Appendix K arrivals of extra-European exporting vessels in Uddevalla are listed. In particular four vessels are of great interest, two from Argentina, one from Chile and one from South Korea. These ships arrive from similar latitudes, and organisms carried in the ballast water tanks and fouling organisms of the hull, might thus have a better possibility to survive and become established in the area.

The number of already existing species and the vigour of existing communities in the area vary greatly when considering different communities. In respect of macroalgae the transect studied annually at Galterö displays a poor species diversity and a sparse vegetation cover (Näslund 1995; see Environmental Profile, section 1.5). For an invading species there might be niches available to exploit. On the contrary the soft bottom community at 37 m depth appears healthy with high abundance and great species diversity (Tunberg 1996, see Environmental Profile, section 1.6). The nearby fjords with anoxic conditions in the deeper layer have much poorer species diversity and abundance of soft bottom animals. If a new organism, tolerant against hypoxic conditions, would be introduced into the area it might become established in the fjords and possibly spread.

Investigations of sediment and organisms in the area show elevated concentrations of various substances. The Stenungsund region is polluted in terms of the heavy metals arsenic, mercury, lead and tin. Concentrations of vanadium are high and the area is classified as moderately polluted to polluted in terms of PAH, PCB and HCB (Cato 1990, NIVA 1996). Investigated macroalgae display an elevated concentration of halogenated alifates, ftalates, isomers of PCB and dibutylftalate. Blue mussels from the area have high tissue concentrations of cadmium and copper and the studies also reveal an elevated concentration of tin in the organisms investigated (cod, *F. vesiculosus*, blue mussel and eelpout; Granmo & Ekelund 1993). The prevalent situation, an area polluted by harmful substances, might increase the risk of establishment of pollutant tolerant NIS in the area.

20.3.4. Dredging of the harbours

The County Administration of Göteborg and Bohuslän permits dredging in the county. When the industries of Stenungsund and the harbours were founded, an extensive dredging occurred. However, during the last decades there have only been applications from the municipality of Stenungsund to dredge the marinas for maintenance purposes. In 1992 the municipality got a ten year permission to dump the dredged sediment between the islands of Almö and Källö underneath the great bridge of Tjörn. The depth of this location is 35 m and it is situated in the waterway between Marstrand and Uddevalla. When dredging work is performed the risk of stirring up sediment, containing resting spores of various organisms, is high. Cysts of several toxic dinoflagellate species have been found in the Stenungsund area. If these fall to the bottom floor where there is no extensive resuspension of sediment, the cysts will eventually become buried underneath a thick layer of sediment and die. Extensive dredging will, on the contrary, give the cysts an opportunity to reach the surface. The effect of an extensive dredging could be an increase of resting spores exported via ships' ballast water from the area of Stenungsund, since it is inevitable that sediment comes along with water when ballasting in shallow areas.

20.3.5. Quantity and origin of the ballast water discharged in the region

Extra-European arrivals in Stenungsund are rare and hence the volume of discharged ballast water of direct foreign origin is small in the area. There is, however, a substantial traffic between Stenungsund and major big ports such as Antwerp, Rotterdam, Hamburg, Bremen etc (Appendix G-I). A vessel with last port of call in any of these harbours intending to export goods from the ports of Stenungsund is carrying water ballasted from those ports. Since these major ports receive a large number of ships from around the world daily, great volumes of water with foreign origin will be discharged in those ports and related waterways. Although these ports are generally heavily polluted some organisms (especially resting stages) may survive even if not establish, and could thus be carried to other areas.

In San Francisco Bay, another huge port with intensive traffic, the number (211) of NIS is much higher than elsewhere on the west coast of North America (Carlton 1996a). Ships arriving from all corners of the world discharge their ballast water in the port of San Francisco and its waterways. The introduced and established species of San Francisco Bay may then spread further to new regions via ships ballasting in the area or as fouling organisms. *Potamocorbula amurensis*, a clam introduced from China in mid 1980's via ships ballast water to the San Francisco Bay, has thereafter been transferred to other areas such as Puget Sound (Carlton 1996b). This scenario shows what is happening in all major ports of the world. Several vessels are en route between the port of Hamburg in Germany and the ports of Stenungsund (Appendix G-I), and many exporting ships arrive in Stenungsund discharging their ballast containing German water. There are approximately 7000 extra-European vessels arriving in Germany annually, whereof 5500 arrive in the port of Hamburg and it has been calculated that nearly 400 000 tons of ballast water of extra-European origin is discharged in the port of Hamburg including the waterway (Gollasch *et al.* in prep.). This indicates that the German water ballasted in the port of Hamburg might contain several exotic species and the region of Stenungsund is not protected from extra-European introductions of exotic species due to its traffic, which is mainly ships en route between NW European ports.

Small amounts of ballast water with extra-European origin are released in the ports of Stenungsund while the quantities are much greater in the port of Uddevalla where a substantial number of ships in ballast arrive from ports outside Europe (Appendix K). Most of the ballast will be discharged within the port of Uddevalla and any organisms surviving the long voyage in the ballast water tank will be released within the area. Stenungsund, and the immediate surrounding, is unlikely to be affected by the water discharged in the waterway en route to Uddevalla (see Harbour Traffic Profile, section 2.2.2). Any species released by ballast water in the port of Uddevalla may spread southward towards the area of Stenungsund.

In a global perspective, looking back at various introductions of foreign species, the Black and Caspian Sea have frequently acted as either recipient or donor regions (see Risk Profile, section 3.1.1. & 3.1.2.). It is therefore important to note that none of the arrivals during the first six months of 1996 either in Stenungsund or Uddevalla, importing or exporting goods, had their last port of call in the Black Sea. This does of course not eliminate the risk of introducing species with Ponto-Caspian origin through sediment on the bottom of the ballast tanks, old ballast water or ballasting in major European ports as discussed elsewhere.

20.3.6. Aquaculture in the area

There are several plants for commercial cultivation of blue mussels (*Mytilus edulis*) in the municipalities of Tjörn, Orust and Uddevalla (Fig. 1). West Sea Products and Skanfjord are the major producers in this area. The maximum yield from 24 cultivation plants in the area is 6 750 tons blue mussels, whereof the major part of the harvest will be exported. The price of mussels varies according to the access but an approximation of the price is 7 SEK per kilo (pers. comm. Key Höglund, County Administration, Göteborg och Bohuslän). This industry is very sensitive to toxic algal blooms and an introduction of yet other toxic species of phytoplankton could have devastating effects.

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APPENDIX A

Dominating phytoplankton species at Havstensfjord, Åstol and Stigfjorden 1992-1997.

Month	Groups/Taxa
January	flagellates and small monades
February	flagellates and small monades, Diatoms; *Skeletonema costatum*, *Thalassiosira nordenskioeldii*, *Chaetoceros* spp.
March	Diatoms: *Skeletonema costatum*, *Thalassiosira nordenskioeldii*, *Chaetoceros* spp, *Leptocylindrus danicus*, *Guinardia* spp., *Ceratulina* spp., *Rhizosolenia* spp., *Eutreptiella braarudii*
April	Diatoms: *Skeletonema costatu*m, *Chaetoceros* spp., *Thalassiosira* spp, *Leptocylindrus danicus*, *Coscinodiscus* spp., *Pseudonitzschia* spp. Dinoflagellates: *Alexandrium* spp., *Gyrodinium aureolum*, *G. spirale* Prasinophyceae, Cryptophyceae, Chrysophyceae
May	Dinoflagellates: *Alexandrium tamarense*, *A. minutum*, *Katodinium rotundatum*, *Dinophysis norvegica*, *D. acuminata*, *Heterocapsa triquetra*, *Scrippsiella* spp. Prasinophyceae, Cryptophyceae
June	Diatoms: *Chaetoceros* spp, *C. socialis*, *Skeletonema costatum*, *Rhizosolenia fragilissima* Dinoflagellates: *Gymnodinium simplex*, *Dinophysis* spp., *D. norvegica*, *Heterocapsa triquetra*, *Ceratium* spp., *Scrippsiella* spp. Cryptophyceae
July	Diatoms: *Skeletonema costatum*, *Proboscia alata*, *Ceratulina pelagica*, *Leptocylindrus danicus*, *Thalassionema nitzchiodes*, *Rhizosolenia fragilissima*, *Chaetoceros* spp., *Pseudonitzschia pseudodelicatissima* Dinoflagellates: *Ceratium tripos*, *C. furca*, *C. fusus*, *Dinophysis norvegica*, *D. acuta*, *Scrippsiella* spp., *Prorocentrum balticum* *Emiliania huxleyi* Cryptophyceae
August	Dinoflagellates: *Prorocentrom micans*, *Ceratium furca*, *C. fusus*, *Dinophysis rotundata*, *D. norvegica* Diatoms: *Proboscia alata*, *Leptocylindrus danicus*, *Skeletonema costatum*, *Chaetoceros* spp., *Pseudonitzschia pseudodelicatissima* *Dictyocha speculum*, *Ebria tripartita*, *Emiliania huxleyi* Cryptophyceae

September	Dinoflagellates: *Prorocentrom micans*, *P. minimum*, *Ceratium fusus*, *C. tripos*, *C. furca*, *Lingoludinium polyedrum*, *Gymnodinium* spp., *Dinophysis norvegica*, *D. acuta* Diatoms: *Leptocylindrus minimus*, *Nitzschia longissima*, *Skeletonema costatum*, *Proboscia alata*, *Chaetoceros radians*, *Pseudonitzschia pseudodelicatissima* flagellates and monades
October	Dinoflagellates: *Prorocentrom micans*, *P. minimum*, *Gyrodinium aureolum* Diatoms: *Asterionellopsis glacialis*, *Leptocylindrus danicus*, *L. minimus*, *Nitzschia longissima*, *Skeletonema costatum*, *Chaetoceros* spp., *Pseudonitzschia pseudodelicatissima* *Dictyocha speculum*
November	Dinoflagellates: *Prorocentrom micans*, *Protoperidinium divergens*, *Katodinium rotundatum*, *Gymnodinium* spp., *Ceratium tripos*, *C. lineatum*, *Polykrikos* spp., *Dinophysis* spp. Diatoms: *Thalassiosira nordenskioeldii*, *Eucampia zodiacus*, *Pseudonitzschia pseudodelicatissima*, *Skeletonema costatum*
December	Cryptophyceae small monades Diatoms: *Chaetoceros* spp., *Rhizosolenia* spp., *Thalassiosira* spp., *Pseudonitzschia pseudodelicatissima*, *P. pungens*, *Leptocylindrus danicus*, *Skeletonema costatum*

APPENDIX B

Distribution and coverage of macroalgae along a transect at 58:06:15 N, 11:48:7 E in 1995. Species missing in the investigation in 1995 but present in 1993 is marked (93) (Näslund 1993, 1995).

< 20 %, ** 20-50 %, *** > 50 %

Taxa/depth	0-1 m	1-2 m	2-3 m	3-4 m
Enteromorpha intestinalis (G)	*			
Ceramium rubrum (R)	*	*		
Elachista fucicola (B)	*** (93)	* (93)		
Ectocarpales	** (93)	** (93)	** (93)	
Fucus vesiculosus (B)	** (93)			
Fucus serratus (B)	*	**	*	
Lithothamnion/Phymatolithon (R)	*	**	***	*
Ulothrix/Urospora (G)	***			
Polysiphonia nigrescens (R)	**	*(93)		
Furcellaria lumbricalis (R)	*	**	**	
Chondrus crispus (R)	**	***	*	
Ahnfeltia plicata (R)		*		
Polyides rotundus (R)		***		
Bonnemaisonia hamifera (R)*		* (93)		
Ralfsia verrucosa (B)	*(93)	*	*	
Cladophora flexuosa (G)		*	*	
Cruoria pellita (R)		*	*	
Laminaria saccharina (B)			*	

G= Green algae, R= Red algae, B= Brown algae

*Introduced species

APPENDIX C

Dominating soft bottom fauna taxa and mean number of individuals per 0.1 m^2 1994-96 (Tunberg 1996).

Taxa	number
Sosane gracilis	255
Polydora caulleryi	61
Montacuta ferruginosa	58
Maldane sarsi	43
Mysella bidentata	38
Ostracoda	32
Ampelisca sp	25
Pholoe minuta	21
Prionospio cirrifera	18
Tunicata	17
Lembos longipes	16
Thyasira sp	15
Amphiura filiformis	15
Dulichia sp	15
Prionospio malmgreni	10
Ampharete finmarchius	9
Scalibregma inflatum	9
Abra alba	9
Modiolus modiolus	7
Nucula nitida	7
Prinospio fallax	6
Trochochaeta muticetosa	6
Ophiura texturata	6
Abra nitida	6
Heteromastus filiformis	5
Myriochele oculata	5
Rhodine gracilor	5
Glycera alba	5

APPENDIX D

Hard bottom fauna, relative coverage 0-20 meters depth, Djurnäs udde 1994-96 (Adolfsson & Tunberg 1994, 1996, 1997).

*present, ** low coverage, ***medium coverage, **** high coverage

taxa/depth (m)	0.5	1	2	3	4	6	8	10	12	14	16	18	20
Mytilus edulis	***	**	**	**	*								
Metridium senile		*	**	**	**	**	**	**	**	**	*	*	
Ciona intestinalis		**	**	***	***	****	****	***	***	***	***	***	**
Echinoidea			*	*	*	*	*	*	*	*	*	*	*
Serpulidae	*	*	*	*		*	*	*	*	**	*	*	*
Asterias rubens	*	*	*	*	*	*	*	**	**	**	*	*	*
Electra pilosa		*	*		***								
Halicondria panicea		*	**	**	*	*	*	***					
Porifera sp		*								*			
Psammechinus miliaris				*				*	*	*		*	
Hydroidea						*	*	*		*	*	*	*
Dendrodoa grossularia							*	*	*	*	*	*	*
Ascidiella scabra							*	*	*	*	*	*	
Sagartiidae								*	*	*		*	*
Tubularia indivisa								*					
Clavelina lepadiformis								*					
Halichondria bowerbanki									**	**	*	*	
Balanus sp										*	*	*	
Modiolus modiolus										*			
Sabella sp										*			*
Buccinum undatum										*	*	*	*
Hyas sp											*		
Alcyonium digitatum												*	
Dentrotonus frondosus													*
Ophiopholis aculeata													*

APPENDIX E

Species, relative and total biomass (g/m^2) of mobile epifauna at Galterö (58:06:35 N, 11:49:34 E) 1985, 1991, 1992, 1995 (Lagenfeldt 1986; 1992; Lagenfeldt & Karlsson 1993, Thörnqvist 1996).

Species/ Year	1985	1991	1992	1995
Crangon crangon	4.44	3.22	4.22	6.59
Platichtys flesus		1.48		
Pomatoschistus microps		0.38	0.57	0.69
Pomatoschistus pictus		0.12		
Pomatoschistus minutus				0.36
Pleuronectes platessa		0.94	1.73	1.01
Pranus flexuosus	0.03	0.41	0.02	0.48
Gobius niger	4.38	2.17	1.09	
Carcinus maenas	8.84	7.93	3.69	
Palaemon adspersus		1.09	0.69	
Palaemon elegans		0.40		
Athansas nitischens		0.10	0.22	
Macropodia rostrata		0.15	0.03	
Anguilla anguilla		1.75		
Siphonostoma typhle	0.04	0.20		
Gasterosteus aculeatus	0.13	0.86		
Creilabrus melops		0.29		
Spinachia spinachia	0.15	0.77		
Scophtalamus rhombus	0.08	0.36		
Number of species	8	18	9	5
Total biomass (g/m^2)	18.09	22.62	12.26	9.10

APPENDIX F

Ships arrival in the port of Vattenfall, Stenungsund, in January to June 1996. FI= Finland, FR= France, GB= Great Britain, N= Norway, NL= the Netherlands, PT= Portugal, Abbreviation used for EES-countries: B= Belgium, D= Germany, DK= Denmark, ES= Spain, S= Sweden.

GT= Gross tonnage

Number of vessels	Last port of call	Ship type	Loading/ Unloading	GT per ship	Next port of call
1	Antwerp B	Chemical Sanitation Ship	Loading	6356	GB
1	Rotterdam NL	Chemical Sanitation Ship	Loading	5696	Rafsnes N
1	Antwerp B	Chemical Sanitation Ship	Loading	6356	Antwerp B
1	Taiwan	Chemical Sanitation Ship	Loading	10734	Karlshamn S
1	Antwerp B	Chemical Sanitation Ship	Loading	6356	Stade D
1	GB	Chemical Sanitation Ship	Loading	3862	GB
2	Lisboa PT	Tanker	Loading	772	DK
4	Rotterdam D	Tanker	Loading	1966	Skagen DK
2	Kalundborg DK	Tanker	Loading	2055	Struer DK
1	Hamburg D	Tanker	Loading	6763	Borgå FI
1	Immingham GB	Tanker	Loading	28292	Borgå FI
11	Rotterdam NL	Tanker	Loading	1666	Hull GB
1	Borgå FI	Tanker	Loading	8630	GB

2	Antwerp B	Tanker	Loading	1881	GB
4	Swansea GB	Tanker	Loading	17679	GB
1	Rotterdam NL	Tanker	Loading	1782	Rotterdam NL
1	Borgå FI	Tanker	Loading	8630	Rafnes N
1	Göteborg S	Tanker	Loading	840	N
1	Hamburg D	Tanker	Loading	2139	N
9	Rotterdam NL	Tanker	Loading	2634	Porsgrunn N
1	Malmö S	Tanker	Loading	1390	N
2	Göteborg S	Tanker	Loading	840	Göteborg S
11	Rotterdam NL	Tanker	Loading	1958	Göteborg S
3	Rotterdam NL	Tanker	Loading	1711	Höganäs S
1	Malmö S	Tanker	Loading	1390	Karlstad S
5	Rotterdam NL	Tanker	Loading	2349	Antwerp B
1	Örnsköldsvik S	Tanker	Loading	2238	Grangemouth GB
1	Rotterdam NL	Tanker	Loading	32612	GB
1	Piteå S	Tanker	Loading	5677	Rotterdam Nl
1	GB	Tanker	Loading	1666	N
1	Nådendal FI	Tanker	Loading	2349	Sarpsborg N
1	N	Tanker	Loading	1390	Karlstad S
1	Göteborg S	Tanker	Loading	2026	Karlstad S
6	Rotterdam NL	Tanker	Loading	1666	Malmö/Trelleborg S
1	FI	Tanker	Loading	8630	Sundsvall S
2	Kotka FI	Tanker	Loading	2634	Hamburg D
2	Kalundborg DK	Tanker	Loading	1468	Kalundborg DK
1	DK	Tanker	Loading	1517	Struer DK
1	Libanon	Tanker	Loading	23741	FR
2	GB	Tanker	Loading	1716	Rotterdam NL
1	FI	Tanker	Loading	8630	Rafnes N

2	Rotterdam NL	Tanker	Loading	2238	Nol Neste Oxo S
1	Malmö S	Tanker	Loading	1390	Varberg S
1	GB	Tanker	Loading	1782	Antwerp B
1	Rotterdam NL	Tanker	Loading	23498	Copenhagen DK
1	Hull GB	Tanker	Loading	2551	FI
2	Lisboa PT	Tanker	Loading	1666	GB
1	FI	Tanker	Loading	8630	Terneuzen NL
1	Malmö S	Tanker	Loading	1390	N
1	Bilbau ES	Tanker	Loading	772	Göteborg S
1	Rotterdam NL	Tanker	Loading	1780	Rotterdam NL
1	Hull GB	Tanker	Loading	1958	Stade D
1	FI	Tanker	Loading	1666	Assens DK
1	GB	Tanker	Loading	2634	Köge DK
1	FI	Tanker	Loading	8630	GB
2	Rotterdam NL	Tanker	Loading	1711	N
2	Rafsnes N	Tanker	Loading	8592	Rafsnes N
1	N	Tanker	Loading	1390	Degerhamn S
1	Göteborg S	Tanker	Loading	2409	Lidköping S
2	Brofjorden S	Tanker	Loading	2117	Brofjorden S
1	Malmö S	Tanker	Loading	1390	DK
3	FI	Tanker	Loading	8630	FI
1	FI	Tanker	Loading	2634	N
1	Rotterdam NL	Tanker	Loading	1174	Poland
4	Libyen	Chemical Sanitation Ship	Unloading	7082	Libyen
1	Mexico	Chemical Sanitation Ship	Unloading	7260	Terneuzen NL
1	Kotka FI	Chemical Sanitation Ship	Unloading	7240	Rotterdam NL
8	GB	Chemical Sanitation Ship	Unloading	3595	GB
2	GB	Chemical	Unloading	3862	FR

		Sanitation Ship			
1	USA Mexican bay	Chemical Sanitation Ship	Unloading	6684	Bremen D
1	Venezuela	Chemical Sanitation Ship	Unloading	6976	GB
1	FI	Chemical Sanitation Ship	Unloading	8661	FI
1	NL	Chemical Sanitation Ship	Unloading	3643	GB
1	Sines PT	Chemical Sanitation Ship	Unloading	5303	Lavera FR
2	Göteborg S	Tanker	Unloading	840	Göteborg S
1	Kalundborg DK	Tanker	Unloading	1517	Kalundborg DK
1	GB	Tanker	Unloading	2238	Örnsköldsvik S
3	Rotterdam NL	Tanker	Unloading	2349	Rotterdam NL
2	Delfzijl NL	Tanker	Unloading	2593	Århus DK
5	Göteborg S	Tanker	Unloading	12929	Göteborg S
1	Fredrikshamn FI	Tanker	Unloading	8630	GB
1	GB	Tanker	Unloading	1958	Copenhagen DK
1	Göteborg S	Tanker	Unloading	4520	Brofjorden S
1	GB	Tanker	Unloading	1958	Helsingborg S
1	Malmö S	Tanker	Unloading	2238	Örnsköldsvik S
1	Malmö S	Tanker	Unloading	1390	N
1	Delfzijl NL	Tanker	Unloading	2593	Kristinehamn S
1	GB	Tanker	Unloading	3206	GB
1	Antwerp B	Tanker	Unloading	1174	Poland
1	Rotterdam NL	Tanker	Unloading	2349	N
1	Rotterdam NL	Tanker	Unloading	1958	Örnsköldsvik S

APPENDIX G

Ships arrival in the port of Borealis, Stenungsund, in January to June 1996. Abbreviation used for EES-countries: D= Germany, DK= Denmark, ES= Spain, FR= France, GB= Great Britain, N= Norway, NL= the Netherlands, PT= Portugal, S= Sweden

GT= Gross tonnage

Number of vessels	Last port of call	Ship type	Loading/ Unloading	GT per ship	Next port of call
1	Terneuzen NL	Tanker	Loading	5537	Stade D
1	Leixoes PT	Tanker	Loading	8434	FR
1	Grangemouth GB	Tanker	Loading	2710	Brest FR
1	Emden D	Tanker	Loading	4901	Belfast GB
1	Sundsvall S	Tanker	Loading	11822	Immingham GB
1	Le Havre FR	Tanker	Loading	25663	Rafnes N
2	Poland	Tanker	Loading	1599	Poland
1	FR	Tanker	Loading	8434	Leixoes PT
1	Sundsvall S	Tanker	Loading	11822	Sundsvall S
2	Brunsbuettel D	Tanker	Loading	4901	Brunsbuettel D
1	Emden D	Tanker	Loading	4901	La Coruna ES
1	FR	Tanker	Loading	11822	Immingham GB
1	Vlissingen NL	Tanker	Loading	8434	Vlissingen NL
1	Brunsbuettel D	Tanker	Loading	4901	Rafnes N
1	Vlissingen NL	Tanker	Loading	8434	Leixoes PT
1	Latvia	Bulk	Unloading	4059	Latvia
1	Estonia	Bulk	Unloading	3197	Göteborg S
1	Sullom Voe GB	Tanker	Unloading	22521	Bergen N
3	N	Tanker	Unloading	1599	N
1	Latvia	Tanker	Unloading	4059	Latvia
1	DK	Tanker	Unloading	5525	Wilhelmshaven D
2	DK	Tanker	Unloading	6355	Slagenstangen N
7	DK	Tanker	Unloading	1517	Kalundborg DK
1	FR	Tanker	Unloading	18526	N
1	GB	Tanker	Unloading	12531	GB

3	N	Tanker	Unloading	9382	Brofjorden S
1	N	Tanker	Unloading	5525	DK
11	Slagenstangen N	Tanker	Unloading	2406	Slagenstangen N
5	Göteborg S	Tanker	Unloading	2907	Göteborg S
1	Kalundborg DK	Tanker	Unloading	2710	Brest FR
5	Kalundborg DK	Tanker	Unloading	3219	Mongstad N
5	Mongstad N	Tanker	Unloading	2710	Kalundborg DK
14	Mongstad N	Tanker	Unloading	2710	Mongstad N
2	DK	Tanker	Unloading	9382	Brofjorden S
2	Slagenstangen N	Tanker	Unloading	2406	Göteborg S
3	Göteborg S	Tanker	Unloading	6720	Brofjorden S
3	N	Tanker	Unloading	23878	GB
1	Mongstad N	Tanker	Unloading	2985	Terneuzen NL
1	Brofjorden S	Tanker	Unloading	1998	Göteborg S
5	Brofjorden S	Tanker	Unloading	1599	Brofjorden S
2	Brofjorden S	Tanker	Unloading	1599	GB
1	Latvia	Tanker	Unloading	4311	Brofjorden S
1	Wilhelmshaven D	Tanker	Unloading	4270	Wilhelmshaven D
1	Wilhelmshaven D	Tanker	Unloading	4270	Göteborg S
3	DK	Tanker	Unloading	5525	Brofjorden S
2	Kalundborg DK	Tanker	Unloading	1468	Vattenfall S
1	DK	Tanker	Unloading	2055	DK
3	Kalundborg DK	Tanker	Unloading	2907	Göteborg S
9	Kalundborg DK	Tanker	Unloading	2489	Kalundborg DK
2	GB	Tanker	Unloading	22500	N
6	N	Tanker	Unloading	20614	N
3	Brofjorden S	Tanker	Unloading	1370	Skagen DK
2	Brofjorden S	Tanker	Unloading	3750	N
2	DK	Tanker	Unloading	5525	Göteborg S
1	Kalundborg DK	Tanker	Unloading	1853	Skagen DK
1	Saudi Arabia Red Sea	Tanker	Unloading	39932	GB
3	Kalundborg DK	Tanker	Unloading	1599	Brofjorden S
2	GB	Tanker	Unloading	39932	GB

1	Slagenstangen N	Tanker	Unloading	1597	Brofjorden S
2	Brofjorden S	Tanker	Unloading	1597	Kalundborg DK
1	DK	Tanker	Unloading	6534	N
1	DK	Tanker	Unloading	6534	Kalundborg DK
2	Brofjorden S	Tanker	Unloading	1597	Slagenstangen N
1	Latvia	Tanker	Unloading	4520	N
2	DK	Tanker	Unloading	5525	Brofjorden S

APPENDIX H

Ships arrival in the port of Norsk Hydro Plast AB, Stenungsund, in January to June 1996. Abbreviation used for EES-countries: B= Belgium, D= Germany, DK= Denmark GB= Great Britain, N= Norway, NL= the Netherlands, S= Sweden.

GT= Gross tonnage

Number of vessels	Last port of call	Ship type	Loading/ Unloading	GT per ship	Next port of call
1	Gävle S	Bulk	Loading	6060	Antwerp B
11	Rafnes N	Tanker	Loading	2551	N
3	N	Tanker	Loading	2551	DK
2	N	Tanker	Loading	2551	GB
1	Husum S	Tanker	Loading	6060	Helsingborg S
2	Gävle S	Tanker	Loading	6060	Norrköping S
1	Gävle S	Tanker	Loading	3554	GB
3	Gävle S	Tanker	Loading	5038	Rotterdam NL
1	Mörbylånga S	Tanker	Loading	3568	Antwerp B
1	Rafnes N	Tanker	Loading	2316	Brunsbuettel D
1	India	Tanker	Loading	10802	Amsterdam NL
2	N	Tanker	Loading	2316	Rotterdam NL
1	GB	Tanker	Loading	1881	Göteborg S
1	Norrköping S	Tanker	Loading	3568	Mörbylånga S
1	Rotterdam NL	Tanker	Loading	3554	GB
1	Husum S	Tanker	Loading	6060	Härnösand S
1	Norrköping S	Tanker	Loading	3554	Rotterdam NL
1	Rafnes N	Tanker	Loading	4259	Helsingborg S
1	Husum S	Tanker	Loading	5038	Rotterdam NL
1	Rafnes N	Tanker	Loading	1461	Skoghall S
1	Rafnes N	Tanker	Loading	4259	Sölvesborg S
1	GB	Bulk	Unloading	2827	DK
2	Delfzijl NL	Bulk	Unloading	2564	NL
1	NL	Bulk	Unloading	2564	N
1	NL	Bulk	Unloading	990	D
1	NL	Bulk	Unloading	2478	Estonia
1	GB	Bulk	Unloading	2827	Hamburg D

3	Randers DK	Bulk	Unloading	2225	DK
1	Runcorn GB	Bulk	Unloading	2827	Hamburg D
1	Delfzijl NL	Bulk	Unloading	2248	Skoghall S
2	Delfzijl NL	Bulk	Unloading	2564	Randers DK
1	DK	Bulk	Unloading	2642	Rostok D
2	Runcorn GB	Bulk	Unloading	2827	Hanstholm DK
1	Delfzijl NL	Bulk	Unloading	990	Poland
1	Harlingen NL	Bulk	Unloading	2250	Åbenrå DK
2	Runcorn GB	Bulk	Unloading	2827	Lithuania
1	Delfzijl NL	Bulk	Unloading	2225	Strömstad S
1	Delfzijl NL	Bulk	Unloading	2361	Rotterdam NL
1	DK	Bulk	Unloading	2642	Delfzijl NL
1	DK	Bulk	Unloading	2829	Skien N
1	Delfzijl NL	Bulk	Unloading	2642	Vattenfall S
1	Norrköping S	Tanker	Unloading	3568	B
1	N	Tanker	Unloading	3023	N
4	N	Tanker	Unloading	3023	GB

APPENDIX I

Ships arrival in the port of Ballast Väst, Stenungsund, in January to June in 1996. Abbreviation used for EES-countries: D= Germany, DK= Denmark, GB= Great Britain, N= Norway, NL= the Netherlands, S= Sweden.

GT= Gross tonnage

Last port of call	Ship type	Loading/ Unloading	GT per ship	Next port of call
Flenburg D	Bulk	Loading	2382	DK
Flenburg D	Bulk	Loading	2516	Wolgast D
Wismar D	Bulk	Loading	1440	DK
DK	Bulk	Loading	1223	DK
DK	Bulk	Loading	2250	Vattenfall S
DK	Bulk	Loading	1698	DK
Vierov D	Bulk	Loading	2061	Amsterdam NL
Greifsvald D	Bulk	Loading	2516	Baltic Russia
Greifsvald D	Bulk	Loading	1055	Copenhagen DK
Bremen D	Bulk	Loading	2642	Vattenfall S
Flensburg D	Bulk	Loading	1582	Seaham GB
Flensburg D	Bulk	Loading	1920	Bremerhaven D
Lübeck D	Bulk	Loading	2473	Helsingborg S
Stralsund D	Bulk	Loading	499	DK
Wismar D	Bulk	Loading	1527	Moss N
Wismar D	Bulk	Loading	1229	Kiel D
Copenhagen DK	Bulk	Loading	1285	Odense DK
DK	Bulk	Loading	931	DK
DK	Bulk	Loading	1285	DK
DK	Bulk	Loading	931	DK
DK	Bulk	Loading	1220	N
DK	Bulk	Loading	1220	DK
Poland	Bulk	Unloading	1345	Landskrona S
N	Tanker	Unloading	2516	Scanraff S

APPENDIX J

Ships arriving from extra European ports in ballast, in order to load in the ports of Stenungsund during the period January to June 1996.

GT= Gross tonnage

BWCAP= Ballast Water Capacity

Port	Number of vessels	Last port of call	Ship type	GT per ship	total BWCAP (tons)
Vattenfall	1	Taiwan	Bulk	10734	4568
Hydro	1	India	Tanker	10802	2057

Sum: 6625 tones of BW

APPENDIX K

Ships arriving from extra European ports in ballast, in order to load in the Uddevalla harbour in January to June 1996.

GT= gross tonnage

BWCAP= Ballast Water Capacity

Number of vessels	Last port of call	Continent	Ship type	GT per ship	total BWCAP (tons)
1	South Korea	East Asia	Bulk	18846	8021
1	India	Central Asia	Bulk	11439	4868
2	India	Central Asia	Bulk	13203	11238
1	India	Central Asia	Bulk	14166	6029
4	Pakistan	Central Asia	Bulk	24787	42196
1	Pakistan	Central Asia	Bulk	26130	11121
1	Israel Mediterranean	West Asia	Bulk	2740	4655
1	Libanon	West Asia	Ro/Ro	15414	4359
5	Saudi Arabia Red Sea	West Asia	Bulk	24787	52745
1	Saudi Arabia Red Sea	West Asia	Bulk	25695	10936
1	Syria	West Asia	Ro/Ro	15414	4359
2	Syria	West Asia	Ro/Ro	15635	8844
1	United Arab Emirate	West Asia	Bulk	27824	11841
2	Ethiopia	East Africa	Bulk	11292	9610
1	Ethiopia	East Africa	Bulk	11731	4993
2	Algeria	North Africa	Ro/Ro	1955	1106
1	Algeria	North Africa	Bulk	3127	1330
1	Egypt Mediterranean	North Africa	Bulk	18858	8026
1	Egypt Mediterranean	North Africa	Bulk	8352	3555
2	Egypt Mediterranean	North Africa	Ro/Ro	15414	8718
1	Egypt Mediterranean	North Africa	Bulk	5091	2167

1	Egypt Mediterranean	North Africa	Bulk	5907	2514
3	Libya	North Africa	Bulk	2916	3723
2	Marocko	North Africa	Ro/Ro	15652	8852
1	Marocko	North Africa	Bulk	1889	804
1	Tunisia	North Africa	Ro/Ro	15652	4426
1	Tunisia	North Africa	Ro/Ro	15414	4359
1	Cyprus	Mediterranean	Bulk	1283	546
2	Ghana	West Africa	Bulk	6742	5739
2	Senegal	West Africa	Bulk	8295	7061
1	The Ivory Coast	West Africa	Bulk	6744	2870
1	Togo	West Africa	Bulk	8295	3530
1	Trinidad Tobago	Central America	Bulk	11455	4875
1	Haiti	Central America	Bulk	11573	4925
1	Honduras	Central America	Bulk	12167	5178
2	Argentina	South America	Bulk	9677	8238
1	Brazil	South America	Bulk	12167	5178
1	Chile	South America	Bulk	9324	3968
1	Columbia North coast	South America	Bulk	4860	2068
				Sum:	**307 429 tones of BW**

21. The Harbour Profile of Klaipeda, Lithuania

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21.1. Introduction

In the south eastern part of the Baltic Sea the port of Klaipeda was chosen for the present study. Sea trade in Klaipeda (former German name - Memel) was initiated in 13th century. Now it is one of the largest and the most northern ice-free ports in the eastern part of the Baltic Sea. Klaipeda State Seaport belongs to the Republic of Lithuania, it handles 100 % of the Lithuanian and nearly 20 % of the sea trade of Russia in the Baltic Sea area.

Klaipeda is a city of about 210 000 inhabitants, with intensive harbour, transport, ship yard, food, building and other types of industry. This is the largest city in the western (coastal) region of Lithuania. In summer the population increases essentially due to tourists visiting the maritime resorts of the Lithuanian coast.

21.2. The harbour environmental profile

21.2.1. Geographical position

Klaipeda port (N 55 43’, E 21 07’, Fig. 1) is situated in the northernmost part of the Curonian (Kursiu Marios) Lagoon, which is a large shallow (mean depth 3.8 m) and mostly freshwater body. The Lagoon is separated from the Baltic Sea by the Curonian Spit. The long (ca. 11 km) and narrow (0.4 - 1.1 km) Klaipeda Strait links the Lagoon to the Baltic Sea (Fig. 2). The seaport occupies the entire eastern (mainland) shore of the Strait. Its territory comprises 10.166 million m^2, which of the water area is 6.232 million m^2 (Klaipeda State Seaport, 1996).

The waterways of the port have been made deeper artificially (max. 12 m depth). In order to maintain them and enlarge the existing port facilities, dredging operations are performed annually, e.g. in 1995-1996 approximately 4.0 million m^3 of bottom sediments (mainly moraine clay with gravel and sand) have been displaced and dumped in the Baltic Sea at a dumpsite (Gulbinskas and Zaromskis 1997).

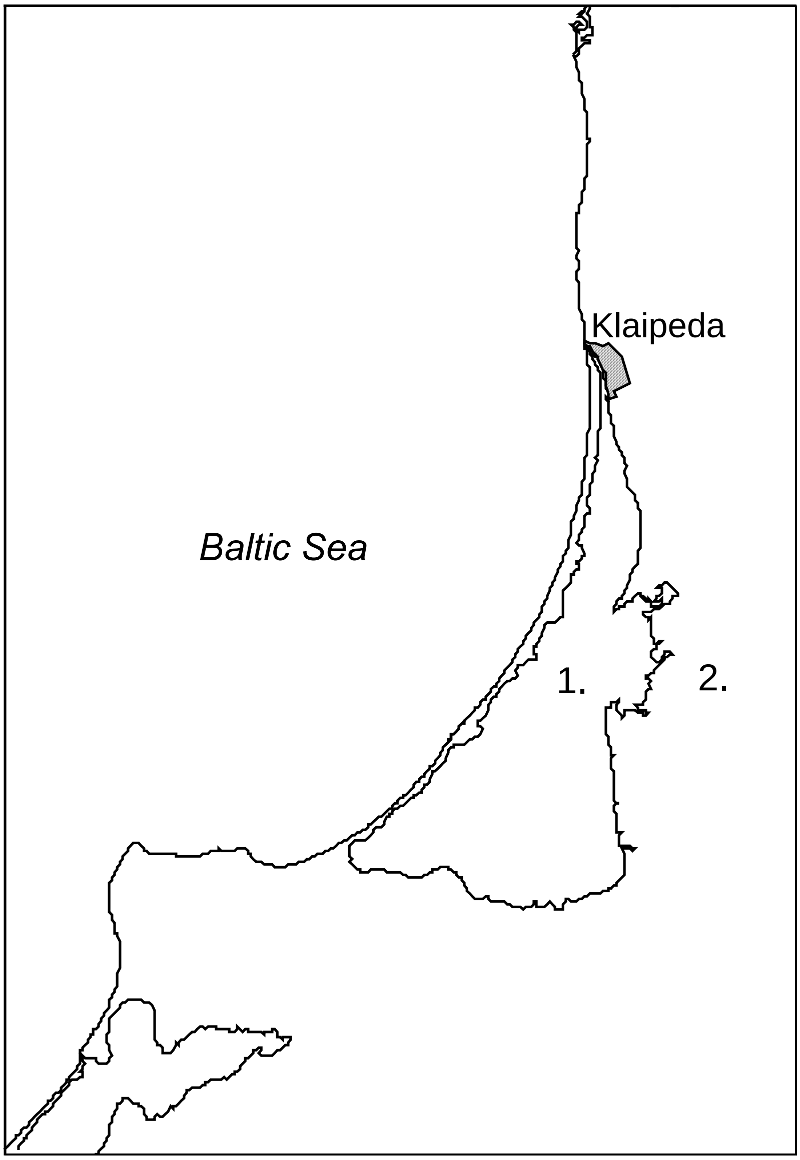

Figure 1. Location of Klaipeda port, 1= Curonian Lagoon and 2=the river Nemunas delta, the south-eastern part of the Baltic Sea.

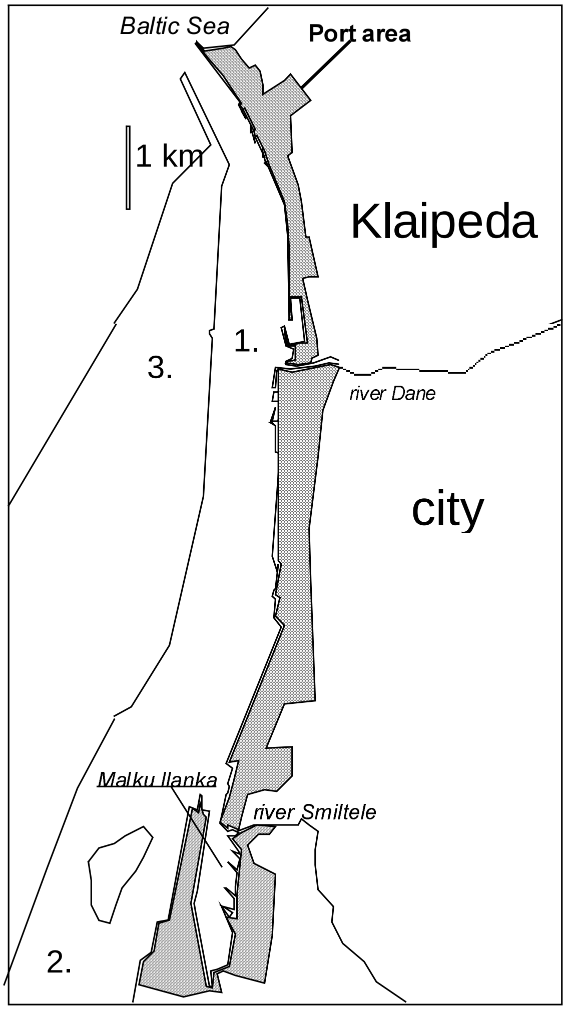

Figure 2. Scheme of the Klaipeda harbour area. 1= Klaipeda Straights, 2=Curonian Lagoon, 3=Curonian spit.

21.2.2. Hydrodynamics and salinity

The Klaipeda Strait is often regarded as the outlet of the river Nemunas, which accounts for 98 % of river water discharge to the Curonian Lagoon. On average, 23 km^3 of the river water pass the Klaipeda Strait per year, and 5 km^3 enters with the sea water inflows (Dubra 1996). In the adjacent sea area the salinity is typical for the Baltic proper, 7-8 PSU. The Curonian Lagoon outflow with lowered salinity (up to 3-4 PSU) may effect the surface layer within a distance of 30-40 km off the outlet (Joksas 1994, Olenina 1997).

As a transition zone between the Lagoon and the sea, Klaipeda Strait is characterised by intensive water exchange. The water is constantly moving either towards the Sea (in 80 % of cases) or to the Lagoon. The speed of the currents in the Strait usually varies within a range of 0.4 - 0.7 m/s, extremes reaching 2.0 m/s (Zaromskis 1996), however, in the harbour inlets the hydrodynamic is weaker, and sometimes stagnant conditions may occur.

The salinity regime is unstable. Depending on wind speed and direction, intensity of the Lagoon's outflow and water level fluctuations, the salinity conditions rapidly change, ranging from mesohaline (>6.5 PSU, occur approximately 70 days per year) to fully limnic (<0.5 PSU, occur 130 days per year) conditions (Dubra 1996). The average annual salinity is 3.6 PSU. The sea water inflows are most abundant during autumn and winter storms, and in summer when water level is low. These intrusions are short term, in 78 % of the cases they do not exceed 2 days (7 days is maximum) (Zaromskis 1996). After the storm the salty water (mixed with the Lagoon's water) returns back to the Sea.

Salinity stratification in the area may occur when the surface layer is filled up by the outflow of the Lagoon's water, and the sea water enter the bottom layer. However, the stratification structures are unstable. An additional freshwater discharge to Klaipeda Strait from the small rivers Dan and Smiltel is of restricted importance, influencing only neighbouring inlets.

It is obvious that because of the special salinity conditions (Tab. 1) only euryhaline alien species, presumably of estuarine origin, and freshwater species that are able to tolerate short term increases in salinity, have a chance to establish in the Klaipeda harbour area.

21.2.3. Water temperature

The temperature regime shows a typical boreal pattern, varying on average within 22°C during a year (Tab. 1) with the highest temperatures (up to 24°C) in July-August and the lowest in January. Temperature stratification of the water column is weak and unstable. In the Curonian Lagoon the range of temperature fluctuations is greater than in the adjacent Baltic Sea coastal area due to thermal inertness of the sea water. The difference in water temperature between the two water bodies may reach 8°C. Thus, the rapid and irregular shifts of water masses in the Klaipeda harbour area cause changes also in temperature (as well as in salinity and other characteristics of the water).

The port is free of ice all year round (as is the adjacent Baltic Sea coastal zone), while the Lagoon is covered by ice from December to March.

In general, the oxygen conditions in the Klaipeda Strait are always normoxic, though oxygen deficiency may occur during calm and warm days in the harbour inlets. For instance, in August 1994 dissolved oxygen concentration of 0.7 mg/l (7 % saturation) was found in a semi-enclosed inlet, the Malku Ilanka, situated close to the Klaipeda sewage water discharge (CMR 1994) (Tab. 2).

Table 1. Salinity, temperature and zooplankton abundance in Klaipeda harbour area in 1995-1996: top - averaged; bottom - minimum and maximum extremes (data from Daunys 1997 and Z. Gasiunaite, unpublished).

Month	Salinity, PSU	Temperature, *C	Zooplankton, 1000 ind./m^3		
			Crustacea	Larvae of *Marenzelleria viridis*	Larvae of *Dreissena polymorpha*
January	0.5 0.4 – 0.6 *	–	–	0	0
February	0.2 – *	2.0 – *	3.9 – **	0	0
March	2.6 0 – 7.3	3.3 1.0 – 5.0	6.1 0.9 – 14.4	8.6 – **	0
April	0.3 0 – 1.6	8.1 5.0 – 13.0	16.3 5.1 – 40.3	0	0
May	0.8 0 – 6.5	11.6 10.0 – 17.0	43.2 23.2 – 64.1	0	0
June	2.8 0 – 6.9	17.6 15.0 – 21.0	48.2 7.1 – 76.3	0	46.4 0 – 106.1
July	3.1 0 – 7.7	17.8 15.0 – 21.0	88.6 4.9 – 232.2	0.03 – **	35.4 4.4 – 81.3
August	1.0 0 – 7.7	20.7 17.0 – 22.0	150.1 3.3 – 199.1	0	26.2 8.8 – 54.8
September	3.0 0 – 7.0	14.5 11.0 – 17.0	38.5 15.4 – 61.9	0.3 – **	0
October	4.5 0 – 7.8	10.9 8.0 – 14.0	21.8 3.3 – 64.1	194.3 18.8 – 520.0	0
November	6.2 1.6 – 7.8	7.2 5.0 – 9.0	9.5 2.7 – 23.2	2.9 0 – 10.1	0
December	4.9 0.5 – 7.9	3.0 2.0 – 5.0	–	1.9 0 – 8.7	0

no data, * literature data (Zaromskis 1996), ** one sample only.

Table 2. Pollution load to the Klaipeda harbour area with suspended solids, BOD_5* and oil products, including oil spills from ships (EPD 1994).

	Years					
	1983	1985	1987	1989	1991	1993
Suspended solids (tons)	7251	9622	6650	6200	5211	2233
BOD_5	8474	8215	6684	6189	4969	3330
Oil products (tons)	36.2	46.0	48.2	63.3	38.9	23.2
Oil spills from ships (tons)	16	11	14	11	8	10

* Biological Oxygen Demand (5 days incubation).

The Secchi depths vary from 0.6 m to 2.4 m, the water is most turbid during summer algal blooms in the Lagoon and most transparent in winter during inflows from the sea (CMR 1995). Nutrient concentrations also depend on what water masses prevail in the Strait, as concentrations are higher in the Lagoon's waters. The highest concentrations of phosphates and nitrates usually occur in early spring and in late autumn, when phytoplankton activity is low (Tab. 3). In 1995, ammonium concentrations that exceeded the 390 µg/l permissible level were found in the Malku Ilanka from April to December, with a maximum of ca. 1000 µg/l in November (CMR 1995).

Table 3. Mean concentration of phosphates, total phosphorus, nitrates, nitrites and ammonia, µg/l, in the surface layer of Klaipeda Straight in 1994-1995 (CMR 1994, 1995)

Month	PO_4	P_{total}	NO_3	NO_2	NH_4
January	78.75	192.5	375	8.55	94.00
February	73.50	80.00	1030	9.80	101.75
March	27.10	72.25	577	7.23	140.75
April	29.16	50.38	1008	10.90	38.61
May	13.06	38.67	279	4.56	23.33
June	30.85	67.00	31	5.41	55.75
July	20.66	55.88	15	3.30	21.69
August	25.99	56.60	27	1.69	57.40
September	32.88	80.38	61	7.25	123.25
October	22.68	53.17	131	10.17	104.83
November	32.86	82.86	256	6.67	135.14
December	-	-	-	-	-

According to bacterioplankton tests the Klaipeda Strait is defined as a mesosaprobic (moderately polluted) area, with tendency to polysaprobity (heavy pollution). The microbial parameters for 1995 in the northern part of the Curonian Lagoon including the Strait are given in Tab. 4.

The chlorophyll a values in surface water were in the range of eutrophic waters (5-40 µg/l) during 1992-1995 (Olenina and Kavolyte 1994; CMR 1994, 1995).

Table 4. Total bacterioplankton abundance (TBA, million cells/l), microbial biomass (MB, µgC/l), abundance of saprophyte (SM, 1000 cells/l) and oil-oxidising (OOM, 1000 cells/l) microflora and abundance of *Echerichia coli* bacteria (*E.coli,* 1000 colonies/l) for March-November in 1995 (CMR 1995)

	TBA	MB	SM	OOM	*E.coli*
Min	0.13	5.37	0.2	0.03	0.2
Mean	2.65	172.79	6.1	2.70	30-60*
Max	7.20	5.34	60.0	60.00	650.0

*range for Klaipeda Straight in May – October

21.2.4. Phytoplankton

Regular observations on the phytoplankton species composition, abundance and biomass in the area are carried out since 1980 to present within the framework of a national environmental monitoring programme (Olenina 1996, 1997; in the section 1.4. these two works are cited, if no other references are indicated).

In total 438 species (including forms and varieties) of plankton algae, belonging to 3 phyla and 11 classes have been found, out of which 343 species were common both in the Lagoon and in the adjacent Baltic Sea areas. Most of the species (37 %) found belong to the fresh-to-brackish and fresh water (42 %) ecological groups. In general, the plankton forms are dominant (76 %), though representatives of benthic and bentho-pelagic groups are also found.

Algal blooms are regular annual phenomena in the Curonian Lagoon, including the Klaipeda harbour area. Usually the algal bloom begins in May and consists of diatoms, the most abundant species is *Stephanodiscus hantzschii* with a biomass reaching 30 mg/l. This corresponds to the intensive algal bloom level (10-100 mg/l) according to Reimers (1990). During the same period in the south-eastern Baltic coastal zone the algal blooms are often caused by the dinophyte *Peridiniella catenata* (biomass up to 90 mg/l), giving the sea water a characteristic brown colour.

In the end of June - beginning of July, when the water temperature in the Lagoon reaches 20°C the bloom of blue-green algae (cyanobacteria) starts, the most abundant species being *Aphanizomenon flos-aquae*. This species does not tolerate intensive mixing of water and currents, therefore calm periods in summer are most suitable for its intensive development. *A. flos-aquae* bloom continues to the end of October - beginning of November, when the temperature of water decreases to 6-9°C. For the period 1984-1996, the biomass of *A. flos-aquae* in the Curonian Lagoon has been at the intensive algal bloom level every summer and exceeded 100 mg/l six times, which is characteristic of hyper-bloom conditions. In the Klaipeda harbour area the highest biomass values (up to 2,000 mg/l) are found in bloom spots in August-October at the mouth of Dan river and in the Malku Ilanka.

Consequently, the risk of inoculation of ballast water by plankton algae is highest from June to September (Table 5). Blue green algae are dominant in phytoplankton in this period, contributing to up to 80-90 % of total abundance (Fig. 3).

Table 5. Seasonal dynamics of the total phytoplankton abundance, 1000 counting units*/l and water temperature in the Klaipeda harbour area in 1984-1996.

Month	Phytoplankton abundance			Temperature, °C	
	mean	min	max	min	max
II	261± 32	215	307	1.6	2.4
III	472 ± 192	216	1136	0.2	2.9
IV	1846 ± 345	875	3332	3.6	12.3
V	6106 ± 623	224	20661	5.0	16.4
VI	8229 ± 3185	326	33988	14.2	19.1
VII	9721 ± 3794	1271	34320	17.5	23.0
VIII	10137 ± 1061	1476	36333	11.8	23.6
IX	12008 ± 3315	2409	**28672	13.1	17.1
X	4799 ± 1233	223	28510	4.9	13.0
XI	4029 ± 839	12	10194	2.3	8.4

* phytoplankton counting units: cells, cenobiums, filaments, colonies, etc. according to (HELCOM 1988);

** maximal abundance in a “bloom spot” was 104 million counting units/l

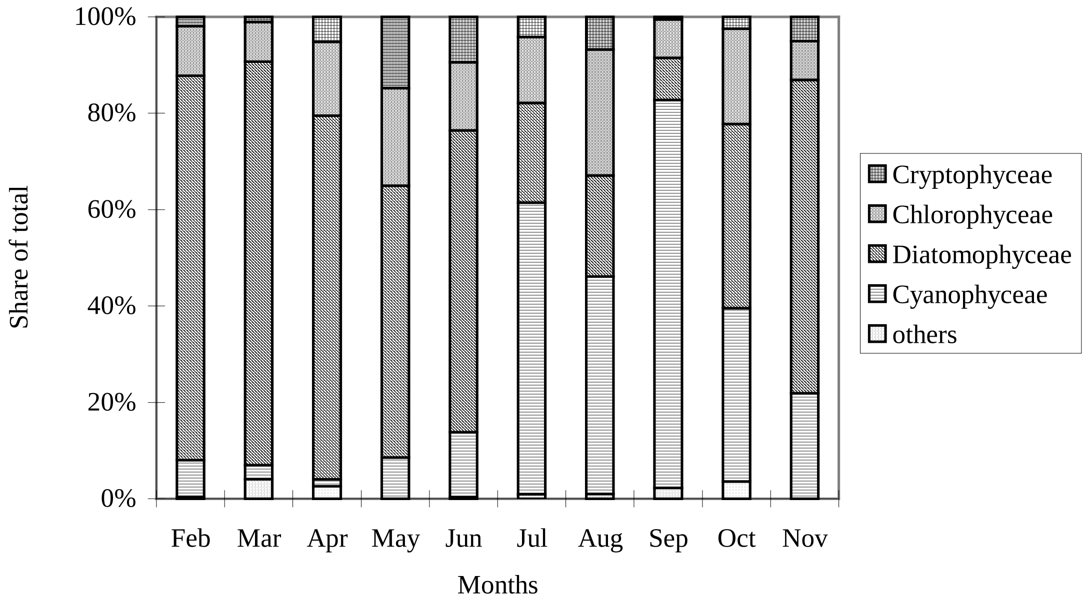

Figure 3. Seasonal phytoplankton succession in the Klaipeda harbour area, based on 1995-1996 observations.

Approximately 4 % of phytoplankton species found in the Klaipeda harbour area are known to be potentially toxic (Tab. 6). However, most of them occur in small numbers. Only a few species reach high abundance: the green algae *Scenedesmus quadricauda* (up to 0.7 million), the blue-greens *Microcystis aeruginosa* (up to 3.2 million), *Anabaena spiroides* (0.4 million) and especially *A. flos-aquae* (up to 400 million).

Table 6. Presence of the potentially toxic phytoplankton species in the Klaipeda harbour area, based on 1984-1996 observations.

	Month/1st - 2nd half of a month																	
	02	03		04		05		06		07		08		09		10		11
	I	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I
Chlorophyceae																		
Scenedesmus quadricauda	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
S. obliquus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Coelastrum microporum	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	-	+
Cyanophyceae																		
Coelosphaerium kuetzingianum	-	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-
Microcystis aeruginosa	+	-	-	+	-	-	-	+	+	+	+	+	+	+	+	+	+	+
M. wesenbergii	+	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	-	-
Snowella lacustris	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Wornichinia naegeliana	-	-	-	-	-		+	+	+	+	+	+	+	+	+	+	-	-
Aphanizomenon flos-aquae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Anabaena flos-aquae	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-
A. spiroides	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-
A. lemmermannii	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	-	-
A. variabilis	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	-	-	-
Nodularia spumigena	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-
Gloeotrichia echinulata	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-
Dinophyceae																		
Dinophysis acuminata	-	-	-	-	-	-	+	+	-	-	+	+	-	-	-	-	-	-
D. acuta	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-
D. norvegica							+											
Prorocentrum balticum	-	-	-	-	-	-	+	+	-	-	+	-	+	-	-	-	-	-
P. minimum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+

Only one species, identified as non-indigenous in the Baltic Sea (Jansson 1994), is found in the Klaipeda harbour area, the dinophyte *Prorocentrum minimum*, which is also known to be potentially toxic. Its highest abundance in the Klaipeda Strait is 0.2 million cells/l (autumn 1995).

21.2.5. Zooplankton

Regular (2-3 times per month) observations on the zooplankton in the Klaipeda harbour area are carried out since the beginning of 1995. In total 44 species and larger taxonomic groups (not identified to the species level) are found. Of them 31 are of freshwater origin and 13 belong to the marine zooplankton.

The species composition, community structure and abundance of the zooplankton depend on water mass and season: for instance, the crustacean zooplankton is usually most abundant in July - August when the Curonian Lagoon water prevail in the Klaipeda Strait (Tab. 1). In Tab. 7 the zooplankton species, showing the highest values of abundance in the study area, are listed and therefore have a great possibility to become ”hot spot” organisms in ballast water. It is of importance that two of them, the polychaete *Marenzelleria viridis* and the zebra mussel *Dreissena polymorpha,* have already shown their great invasive potential, during some periods their plankton larvae are the dominant group of zooplankton in the Klaipeda harbour area.

Table 7. Most abundant species and taxonomic groups of zooplankton in the Klaipeda harbour area during 1995-1997.

Most abundant species and taxonomic groups	Max. densities*
Freshwater zooplankton	
Daphnia longispina	39.8
Chydorus sphaericus	145.9
Leptodora kindti	2.3
Mesocyclops leuckarti	48.1
Keratella sp.	120.1
Brachionus sp.	254.2
Dreissena polymorpha larvae	106.1
Marine zooplankton	
Acartia bifilosa	21.7
Marenzelleria viridis larvae	520.0

*1000 ind/m^3

21.2.6. Benthic macrofauna and flora

Historical data on benthic macrofauna in the Curonian Lagoon and the Lithuanian coastal zone is available since the early 1950s; regular observations on species composition, abundance and biomass have been carried out since 1980 as a part of the national environmental monitoring programme (Olenin 1987, 1997 and unpubl.). In total 48 species or higher taxa of benthic invertebrates, not identified to species level, are found in the Klaipeda Strait.

The macrofauna is a mixture of marine and freshwater species. It exists in an extremely varying environment of frequently changing salinity, accumulating industrial and communal wastes, dredging operations, etc. Therefore, there is a whole set of benthic habitats available for different macrofaunal assemblages: hard artificial and semi-natural substrates (piles, sunken wood, embankment boulders) fouled by non-indigenous species such as the barnacle *Balanus improvisus*, the hydroid *Cordylophora caspia*, and the zebra mussel *Dreissena polymorpha*, sands and mud inhabited by burrowing organisms, such as oligochaetes, the polychaetes *Nereis diversicolor* and *Marenzelleria viridis*, etc. (Olenin & Leppäkoski 1999). In some places inside the harbour inlets the macrofauna is absent because of heavy organic pollution. Each of the benthic communities is characterised by a certain level of species diversity, abundance and biomass of the organisms. The most diverse and abundant is the fouling community of *B. improvisus* with biomass values up to 133 g/m^2 and up to 19 species found in one sample. Quantitative characteristics of the most common soft bottom community in the area are presented in Tab. 8.

Table 8. Mean abundance and biomass of a soft bottom community in the Klaipeda harbour area.

	Abundance		Biomass		Occurrence
Species (taxa)	ind./m²	%	g/m²	%	%
Oligochaeta	10220	64	6.47	30	98
*Nereis diversicolor**	180	1	1.99	9	66
Ostracoda	130	1	0.33	2	46
Balanus improvisus	200	1	4.17	19	24
Corophium (C. volutator, C .curvispinum)	1130	7	1.19	6	73
Chironomidae	1020	6	2.18	10	80
Mya arenaria	250	2	0.24	1	25
Others (40 species)	2880	18	4.95	23	
Total	16010		21.52		

*large specimens of the polychaete cannot be caught

The littoral zone of the whole area has been altered, now the shoreline is formed of either concrete blocks or granite boulders, and no natural benthic macrophyte communities are left. In summer time the blocks and boulders are fouled by seasonal opportunistic filamentous green algae *Cladophora* and *Enteromorpha*.

21.3. The harbour traffic profile

Information on the ships traffic was obtained from the Klaipeda Sea Port authorities (Klaipeda State Seaport 1996, Klaipeda 1997).

21.3.1 Foreign traffic

Every year about 7,000 ships enter Klaipeda port (Table 9) from about 50 countries. The port is able to accommodate ships of up to 195 m in length with draught of 10.5 m.

Table 9. Ship traffic and cargo turnover in Klaipeda port in 1994-1997

	1994	1995	1996	1997*
Ships entered, total	6884	6931	7170	-
Ships loaded/unloaded	4733	5058	5649	2873
Cargo turnover, 1000 tons				
Unloaded	2799	2619	3256	-
Loaded	11710	10090	11573	-
Total	14502	12709	14829	7730
Transit, 1000 tons	11105	8274	10471	-
Export, 1000 tons	2688	3185	2957	-
Imports, 1000 tons	716	1250	1401	-
Liquid bulk turnover, 1000 tons	4915	2728	4195	1437

in the1st half-year

Ferry lines (mostly cargo) operate between Klaipeda and German (Kiel, Travemünde, Mukran), Swedish (Ahus, Stockholm) and Danish (Copenhagen, Fredericia) ports. By regular shipping lines Klaipeda port is linked with some other ports in the Baltic Sea (Gdynia, Poland and Flensburg, Germany), North Sea (Hull and Felixtowe, Great Britain; Bremerhaven and Hamburg, Germany; Rotterdam, the Netherlands, etc.), Biscay Gulf (Bilbao, Spain) and some ports outside Europe: at the east coast of North America, north-west Africa and South East Asia.

About 70 % of the total cargo volume is transit, 20 % export and 10 % import (Tab. 9). The most important cargo are oil products, metal and fertilisers (Tab. 10).

No shipping lines exist between Klaipeda and the Black Sea ports, however, vessels from this region call Klaipeda every year. No foreign trade is presently performed via inland water ways.

Table 10. Cargo flow structure in Klaipeda port in 1996

Cargo handled	Share, %	Turnover, 1000 tons
Oil products	26.7	3956
Metal	23.6	3496
Fertilisers	11.1	1651
Frozen products	5.7	842
Timber	3.6	537
Cereals	3.0	440
Sugar	2.7	404
Containers	2.6	385
Scrap metals	2.3	342
Cement	2.0	293
Inland shipping	0.1	18
Other cargo	16.6	2465

21.3.2 Domestic traffic

The domestic traffic utilises the inland waterway ” Klaipeda - the Curonian Lagoon - Nemunas river”. During summer, fast-going passenger boats (hydrofoils) connect Klaipeda with small towns on the Curonian Spit and with Kaunas (the 2nd largest city of Lithuania, nearly 600,000 inhabitants). The cargo ships are flat bottomed barges with the draught less than 2 m, with no ballast tanks. In general, the domestic traffic is of small importance, contributing only 0.1 % of the annual total cargo volume in Klaipeda Sea Port (Tab. 10).

21.3.3 Ballast water treatment

No information on ballast water discharges in the Klaipeda harbour area is available, since neither Klaipeda Sea Port Authority nor environmental control institutions register the volumes of ballast waters uptake or release. The polluted ballast waters are collected from oil tankers and treatment is provided by the stock company ” Klaipeda Nafta”, their volume varies within 20-30,000 m^3 per year. These waters are least suitable for living organisms, while so called ”conventionally clean” waters, potentially containing alien organisms, may be released by the tankers in the sea in the immediate vicinity of the harbour or in the port itself.

Tab. 9 and 10 show that Klaipeda is rather a recipient than a donor of ballast water: the volume of the loaded cargo is ca. 4 times higher than that of unloaded cargo. The two most important types of cargo (crude oil, oil products and metals) are exported from the port and the import of liquids is by far less than their export. At present only a very rough estimation can be made. Taking into account the cargo volumes, it can be assumed that the ballast water volume released would be 2-4 million tons per year.

21.4. Risk profile

Most of the regular shipping and ferry lines connect Klaipeda with ports in the southern Baltic and North Seas, which are situated practically in the same climatic zone. Therefore, the temperature differences should not be a factor preventing the introductions.

Varying salinity forms quite special conditions, but regardless of that most successful introductions into the Klaipeda harbour area (Tab. 11) are of estuarine origin, and therefore new introductions of estuarine organisms are most probable.

Table 11. Alien species in the Klaipeda harbour (underlined) and the adjacent area* of the Curonian Lagoon

Ecological group	Taxonomic group	Species	Characteristic
Phytoplankton	Dinophycea	*Prorocentrum minimum*	with inflows of the sea water, up to 0.2 million cells/l
Epifauna	Hydroida	*Cordylophora caspia*	dense foulings on hard substrates, no quantitative data
	Polychaeta		
Infauna	Spionidae	*Marenzelleria viridis*	muddy habitats, up to 840 ind./m^2 (1.24 g/m^2) in the grab samples taken in the Straight; up to 462 ind./m^2 and 573.8 g/m^2 in the core samples in the Lagoon (Daunys 1997)
	Crustacea		
Epifauna	Cirripedia	*Balanus improvisus*	dense foulings on hard substrates, up to 5560 ind./m^2 107.52 g/m^2
Nektobenthos	Mysidacea	*Paramysis lacustris*	littoral zone of the Lagoon, no quantitative data
--‘--	--‘--	*Limnomysis benedeni*	--‘’—‘’--
--‘--	--‘--	*Hemimysis anomala*	--‘’—‘’--
Epifauna/nekto-benthos	Amphipoda	*Corophium curvispinum*	occurs on all substrates, most dense population (up to 37000 ind./m^2) wound in foulings of *Cordylophora*
--‘--	--‘--	*C. multisetosum*	no quantitative data
Nektobenthos		*Pontogammarus robustoides*	in floating mats of filamentous green algae the common biomass of *Pontogammarus and Chaetogammarus* reaches 120 g/m^2 (D. Daunys, pers. comm.)
--‘--	--‘--	*P. crassus*	--‘’—‘’--
--‘--	--‘--	*Chaetogammarus ischnus*	--‘’—‘’--
--‘--	--‘--	*C. warpachowskyi*	--‘’—‘’--

Epifauna/nekto-benthos	Decapoda	*Rhithropanopeus harrisi*	no quantitative data
--‘--	--‘--	*Eriocheir sinensis*	no quantitative data
Epifauna	Gastropoda	<u>*Potamopyrgus antipodarum*</u>	up to 13200 ind./m^2 and 38.6 g/m^2 on muddy bottoms
Epifauna	Bivalvia	<u>*Dreissena polymorpha*</u>	up to 30500 ind./m^2 (9.80 g/m^2) in the grab samples; the biomass is higher (hundreds g/m^2) in dense fouling on hard substrates in the mouths of rivers Dan and Smiltel
Infauna	Bivalvia	<u>*Mya arenaria*</u>	up to 3560 ind./m^2 and 3.16 g/m^2 on sandy/muddy bottoms, population unstable

*within 10 km to the south from Klaipeda Straight

The study area is characterised by a great variety of different biotopes: from heavily polluted muddy bottoms to clean sand, artificial hard substrates suitable for the establishment of fouling organisms, and from normal Baltic Sea conditions to local fresh water outlets.

We can state that Klaipeda port is heavily ”polluted” with alien species. Besides 8 species found at the monitoring stations (Tab. 11, underlined), 10 other species are included which are known to occur in the vicinity of the Klaipeda harbour area, and therefore could be found (e.g. in drift) in the port too. Most of the alien species belong to different groups of zoobenthos (epifauna, infauna or nektobenthos).

Species, which form stable and dense populations and foul hydrotechnical constructions and hulls of the ships, *C. caspia*, *B. improvisus* and *D. polymorpha*, are of most importance from the economic point of view. A native fouling organism, the bivalve *Mytilus edulis* do not occur in the Klaipeda Strait in large densities (because of too low and unstable salinity), only small numbers of juvenile individuals are found in the port close to the sea gates. Thus, it can be concluded that the fouling animal organisms in all of the area are represented by the alien species.

The polychaete *Marenzelleria viridis* should also be mentioned, which has become the dominant species of biomass in muddy sediments on the southern border of the Klaipeda Strait. It has changed the structure of the bottom sediments, burrowing as deep as 40 cm into the sediment, where the native invertebrates (oligochaetes and chironomids) were able to dig only to 5-7 cm (Daunys 1997, Olenin and Leppäkoski in print).

The intentional introductions of the Ponto-Caspian crustaceans (mysids and gammarids) to the Curonian Lagoon, undertaken in 1960s (Kublickas and Bubinas, 1985), had little effect on the ecosystem of the Klaipeda Strait.

During the period of regular sampling of phytoplankton and zoobenthos in the framework of monitoring programme since 1980 to present, no primary introduction of an alien species was observed in Klaipeda port. For instance, two of the latest newcomers, dinophyte *Prorocentrum minimum* and polychaete *M. viridis* were first revealed in the western parts of the Baltic Sea, in 1981 and 1983 respectively (cf.

Jansson 1994), whereas they appeared in the Lithuanian coastal waters in 1993 (Olenina 1997) and 1989 (Olenin and Solovjeva 1994).

Further detailed research is needed to find out both the economic and ecological scope of the problem of the ballast water releases in Klaipeda port. From studies made in similar conditions (Gollasch 1996), we know that it can be of great importance.

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22. The ports of Southwest Finland - Turku, Naantali and Pargas

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22.1. Introduction

The three ports of SW Finland chosen for this study, Turku, Naantali and Pargas, are all situated in the inner archipelago zone. Ships heading for the harbours must pass through the Archipelago Sea, which is the largest and most island-rich archipelago area of the whole Baltic Sea (Fig. 1 and 2). This means that they have to move along a >100 km long route with many narrow passages before they reach the harbours.

Ondatra zibethica, the muskrat

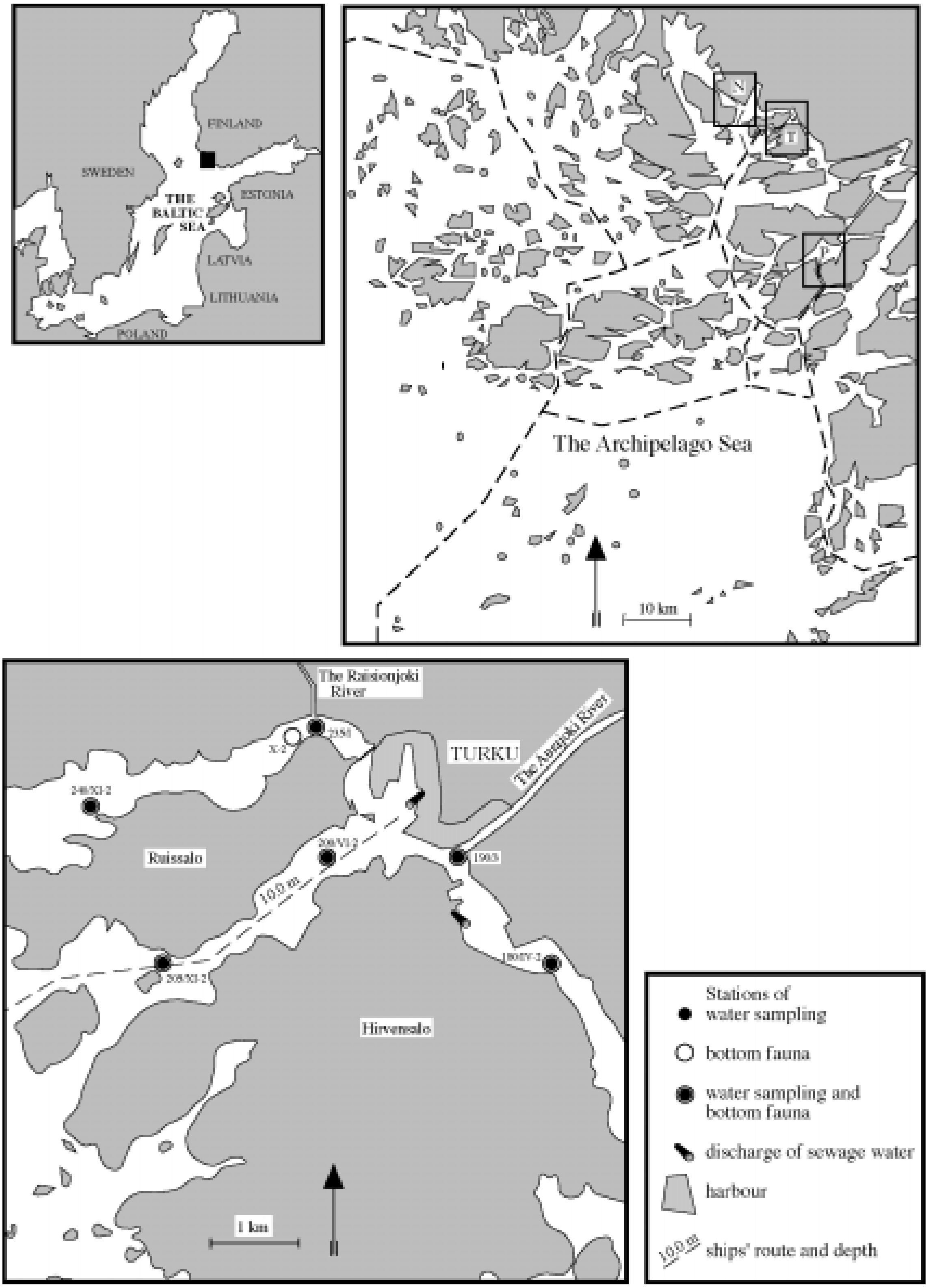

Figure 1. Overview map of the three harbours studied in SW Finland, N Baltic Sea, and detail map of the port of Turku. Numbers of sampling stations refer to the surveys of water quality and bottom fauna by Räisänen & Jumppanen (1996) and Räisänen (1997).

Turku is a city of about 160 000 inhabitants, whereas Naantali and Pargas are minor towns with populations of 13 000 and 12 000, respectively. The harbours differ considerably in size and structure of ships' traffic. The port of Turku has the most intensive traffic due to the large car and passenger ferries on the Turku-Mariehamn-Stockholm line and the numerous visits of ro-ro carriers from Germany. The ships' traffic of the Naantali and Pargas harbours is dominated by cargo vessels transporting mainly oil, coal, cement, grain and containers.

22.2. Environmental profile

In the following chapters a description of physical, chemical and biological conditions of the harbour areas is given. The source of environmental data is two research reports from the Water Protection Association of SW Finland on benthic macrofauna, water quality and primary production (Jumppanen & Mattila 1994, Räisänen 1997, Räisänen & Jumppanen 1996) if no other reference is indicated.

The water areas of the three ports are characterised by narrow sounds and shallow inlets. The dredged harbour areas and the ships' routes represent the deepest parts of the archipelago areas off Turku, Naantali and Pargas. The shores in the region are typically covered by dense stands of reed which extend far into the water in shallow areas.

22.2.1. Salinity

There are several major freshwater discharges from rivers, the most important being the Aurajoki River which empties directly into the harbour area of Turku (Fig. 1). The long-time annual mean discharge of fresh water from the Aurajoki River is estimated at 7,2 m^3/s. The flow, however, shows considerable seasonal variations with peaks during the snow melting period in March - April and during heavy rain falls in the autumn. This is reflected in great salinity fluctuations of the harbour water with a surface salinity varying from 1,8 to 6 ‰ outside the river mouth in 1995 (Tab. 1). The same pattern was seen outside the smaller Raisionjoki river mouth about one km NW of the harbour. During the time of major freshwater outputs from the rivers a clear salinity stratification can be observed in the harbour area (Tab. 1).

In the port areas of Naantali and Pargas the fresh water discharges are smaller and thus the seasonal salinity variations and stratification patterns are less pronounced than those of the port of Turku (Tab. 1).

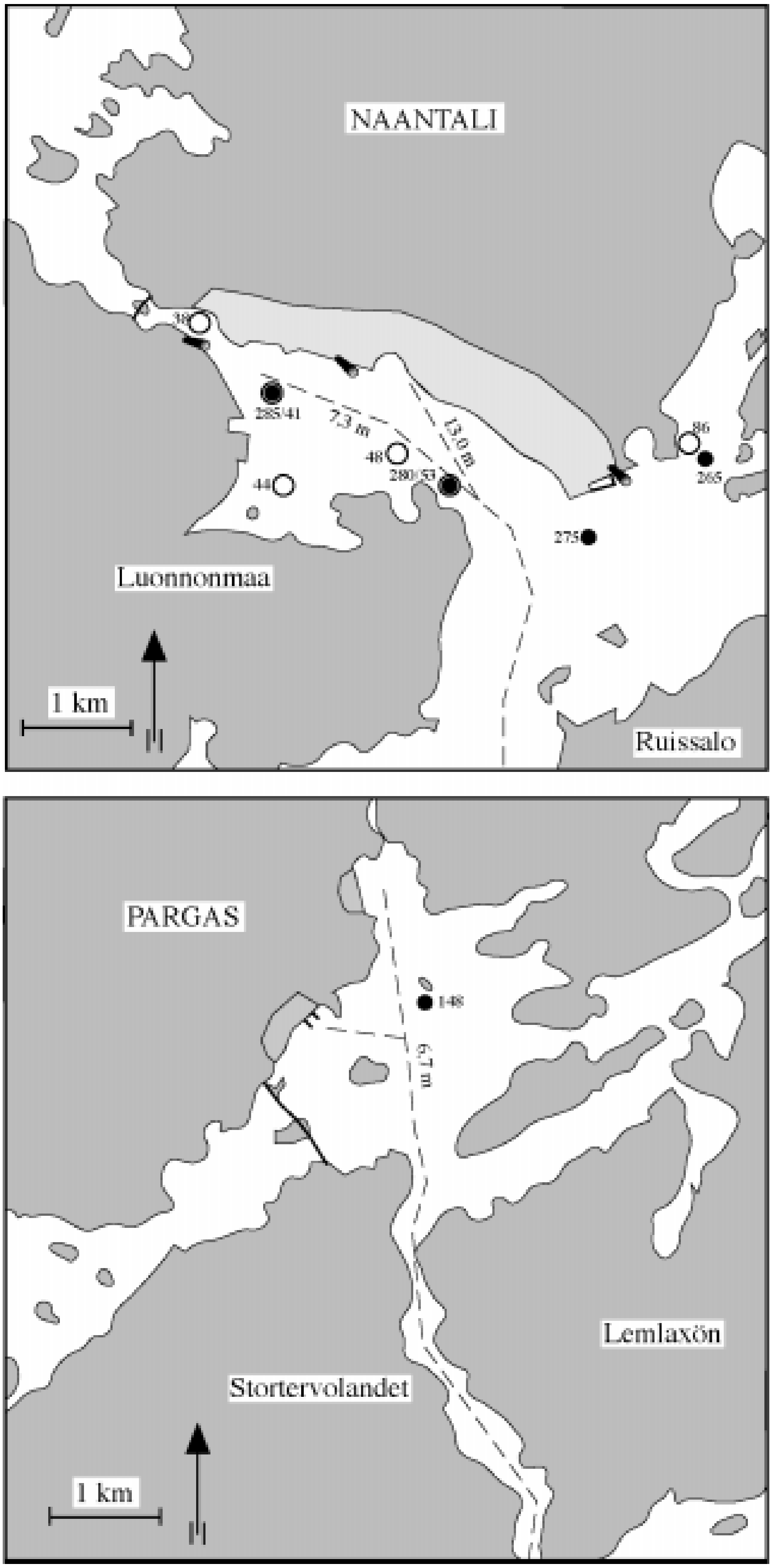

Figure 2. The port areas of Naantali and Pargas. Explanations as in Fig. 1.

Table 1. Hydrographic data, nutrient concentrations and chlorophyll a content in the harbour waters of Turku, Naantali and Pargas in 1995 (Räisänen & Jumppanen 1996). Numbers of sampling stations as in Fig. 1 and 2. The sampling stations in Turku are divided into 1= 190, 180, 200; 2= 235; 3= 205, 240. The sampling stations in Naantali are divided into 1= 280, 285; 2= 265, 275.

Port of Turku

Date	Station no.	Secchi depth (m)	Depth (m)	Temp. (°C)	Salinity	Tot. N (µg/l)	Tot. P (µg/l)	Chlor. a (µg/l)*
6.3.95	1	0.3-0.4	1	0	2-3.5	1400	63-103	
			7	0.1	5	980	44	
			10	0	5.5	740	43	
	2	0.2	0.5	0.2	0.5	2100	102	
			1.5	0.2	4	1300	56	
	3	0.2-0.7	1	0.1-0.2	4-4.5	970-1200	43-51	
			9	0.2	5.7	620	30	
			10	0	5.4	660	36	
6.6.95	1	0-0.5	1	18.1-19.4	2.5-3.5	1600-2600	73-200	3-65
			2	17.8	3.5	1600	63	
			7	7.2	3	970	70	
	2	0.1	1	16.7	1.5	3000	270	
			2	13	3.5	1700	120	
	3	0.1	1	12.2	4	1600	87	21
			10	6.3	4	430	29	
4.7.95	1	0.6-0.8	1	15.7				
			0-2	15	5		59-65	21.3-23
	2	0.7	1	15.5				
			0-2		5.5		55	20.1
	3	0.7-0.8	1	15.6-15.7				
			0-2		5.5	520	39-52	5.5-17.6
8.8.95	1	0.3	1	18-18.9	5.5	950-1000	69-96	19-24
			2	18.6	5.5	1000	98	
			7	18.9	5.5	1000	66	
	2		1		5.5	970	79	
			2	19.3	5.5	960	77	
	3	0.6-0.7	1	18.5-19.5	5.5	440-460	43-51	14-17
			9	17.6	5.5	460	48	
			10	17.8	5.5	400	44	
2.10.95	1	0.8-0.9	1	10.8-11.3	6	850-1100	41-46	
			2	10.8	6	1000	47	

		8	11.4	6	1100	50
		11	11.2	6	800	40
2	1	1	10.8	6	740	43
		1.5	10.9	6	660	44
3	1-1.2	1	11.1-11.3	6	460-520	34-37
		10	11.1-11.3	6	420-520	31-35

*pooled sample from the productive water layer

Port of Naantali

Date	Station no.	Secchi depth (m)	Depth (m)	Temp. (°C)	Salinity	Tot. N (µg/l)	Tot. P (µg/l)	Chlor. a (µg/l)*
7.3.95	1	1.1-1.3	1	0.3	4.5	930-1000	33-39	
			27	0.1	6	460	40	
			32	0	6	410	31	
	2	0.7-4	1	0.3-0.4	3.5-4	1000-1600	44-46	
			7	0.2	5.5	600	31	
			10	0.1	6	550	28	
6.6.95	1	1.3	1	16.9-17.4	4.5-5	690-730	24-26	9.5-12
			27	4.7	5.5	400	23	
			32	5.2	5.5	380	23	
	2	0.7-1.1	1	18.1-18.3	4	810-1000	26-43	13-36
			7	8.2	4.5	580	40	
			9	7.2	4.5	490	26	
4.7.95	1	0.9	1	14.5-14.6				
			0-2		5.5		26-27	5.5-14.9
	2	0.9-1	0.6	15				
			1	14.7				
			0-2		5.5-6	410	30-55	14.9-19.2
8.8.95	1	0.9-18	1	17.9-18.4	5.5	380-400	28-31	5.5-12
			26	10.8	5.8	540	48	5.8
			32	9.2	5.8	560	43	
	2	0.3-0.7	1	18.1-18.2	5.5	400-550	34-56	19-24
			7	18	5.8	450	48	
			9	15.6	5.5	420	31	
2.10.95	1	1.2-1.6	1	11.9	6	390-400	27-28	
			26	11.6	6	380	41	
			32	11.4	6	420	28	
	2	1.2	1	11.5-12	6	380-440	32-38	

			7	11.3	6	470	34	
			9	11.3	6	390	32	

*pooled sample from the productive water layer

Port of Pargas

Date	Station no.	Secchi depth (m)	Depth (m)	Temp. (°C)	Salinity	Tot. N (µg/l)	Tot. P (µg/l)	Chlor. a (µg/l)*
7.3.95	148	1	1	0.6	4.1		38	
			4	0.3	5.3		29	
5.6.95	148	1.9	1	20	5		18	2.1
			5	10.5	5.2		27	
7.8.95	148	0.9	1	20.4	5.7		32	7.9
			4	23	5.7		30	

*pooled sample from the productive water layer

The surface salinity in summer and early autumn in the three harbour areas lies just below that of the Archipelago Sea (long-time mean 6-7 ‰) and the N Baltic Proper (7-7,5 ‰) (Haapala & Alenius 1994), whereas it is considerably lower during other times of the year, particularly in the port area of Turku.

22.2.2. Temperature

A permanent ice-cover occurs every year in the inner parts of the Archipelago Sea. The number of real ice days in the three harbours varies a lot from year to year as shown in the following table (data from Seinä *et al.* 1996).

Year	1990-91	1991-92	1992-93	1993-94	1994-95
Turku	80	43	71	126	49
Naantali	80	44	77	143	48
Pargas	72	41	77	121	52

Of these winters only that of 1993-94 was considered to be an average one with regard to the maximum annual extent of ice cover in the whole Baltic Sea, the other ones being mild or extremely mild (Seinä & Palosuo 1996). In the harbour areas and along the narrow ships' routes the movements of broken ice result in severe scouring of the shores, which strongly affects littoral plant and animal communities.

In summer surface temperature in the harbour areas often reaches about 20 °C (Tab. 1.) depending on air temperature and wind conditions. In 1995 temperature stratification occurred on the deeper sampling stations of the ports of Turku and Naantali, the difference between surface and bottom water being occasionally >10 °C.

Places where cooling water from power plants or warm wastewater from water treatment plants is discharged are known to be favoured by introduced species from warmer sea areas. In Turku and Naantali this kind of potential habitats for NISs is represented by two wastewater outlets in each harbour (Fig. 1). Also, there is an important discharge (7 m^3/s) of cooling water (average temperature increase 3,1 °C) from the coal fired power plant in the port of Naantali. At these sites the temperature is considerably higher than in the surrounding waters and no ice is formed during the winter.

22.2.3. Trophic status of the harbour waters

The inner parts of the Archipelago Sea are heavily loaded by nutrient discharges mainly from agriculture and sewage treatment plants. In the year 1995 the total phosphorus and nitrogen load (atmospheric fallout not considered) on the sea area off Turku was estimated at 143 and 2262 tons, respectively. The phosphorus load was dominated by the runoff from cultivated fields transported to the sea mainly by the Aurajoki River (48 % of the total load) and to a lesser extent by the smaller rivers of the region. The phosphorus contribution from the sewage treatment plants has decreased since the early 70s because of improvements of the cleaning processes. In 1995 the phosphorus discharges from the plants constituted only 15 % of the total load. However, when the nitrogen load is considered, the main source is wastewater plants, their share being estimated at 43 % in 1995. The nitrogen contribution of the Aurajoki in the same year was 31 %.

In 1995 total nitrogen concentration on the water sampling stations in the Turku harbour exceeded 1000 µg/l on many occasions, particularly on the stations situated near the river mouths and the sewage water discharge points (Tab. 1, Fig. 1). Also, the phosphorus concentrations were high, often exceeding the 80 µg/l limit for very eutrophicated waters. The nutrient concentrations in the Naantali and Pargas harbours were clearly lower than those measured in the port of Turku.

The chlorophyll a -values in pooled samples from the productive water layer were in 1995 within the range of eutrophic waters (5 - 25 µg/l) in all three harbours, with the exception for a few extremely high values during the algal spring bloom in early March. The high chlorophyll values together with high concentrations of particular organic matter originating from the rivers resulted in low Secchi depth values, particularly in the Turku harbour where the Secchi depth in most cases were only a few dm and exceeded 1 m only in October.

The harbour areas and the entire inner archipelago zone were classified as eutrophic in 1995 when measured as primary productivity during the ice-free season. Thus, the values obtained varied within the range of 300 - 1500 mgC/m^3d. When the general fitness for use of the water was considered, as a combination of Secchi depth, turbidity, concentrations of oxygen, chlorophyll a, total phosphorus and bacteria, the harbour area of Turku was classified as satisfactory and those of Naantali and Pargas as good.

22.2.4. Phytoplankton

In the investigations of 1995 the phytoplankton biomass in May was dominated by diatoms, as usually in the Baltic during the spring bloom. The most abundant species were *Sceletonema costatum*, *Achnanthes taeniata* and *Chaetoceros wighamii*. At this time also dinoflagellates constituted an important part of the phytoplankton biomass.

Tab. 2. shows two examples of phytoplankton species composition in early June on one locality near the port of Turku and one locality in the Naantali port area. In the investigations in 1995 Cryptophyceae, diatoms, Prymnesiophycea (*Chrysochromulina* sp.) and green algae dominated the phytoplankton communities of the inner archipelago zone during the summer season. The share of the blue green algae was only about 1 %. At the sites of sewage water discharge in the ports of Turku and Naantali the dominating phytoplankton group was *Eutreptiella* sp., a genus typically occurring in polluted water.

Of the species recorded in the harbour waters no one belongs to the non-indigenous species of the Baltic Sea (Jansson 1994). Only a few potentially harmful genera were found, e.g. *Anabaena*, *Aphanizomenon* and *Chrysochromulina*, which are known to be potentially toxic. So far there have been no reported blooms of toxic phytoplankton in the harbour areas.

Table 2. Examples of phytoplankton species composition close to the port of Turku (station 180) and in the port of Naantali (station 275) 6.6.1995 (Räisänen & Jumppanen 1996). For more information on abundance and biomass consult the list on http://www.abo.fi/fak/mnf/biol/www-sidor.html

CYANOPHYCEAE	BACILLARIOPHYCEA
Planktothrix mougeotii	*Chaetoceros tenuissima*
Merismopedia warmingiana	*Coscinodiscus granii*
CRYPTOPHYCEAE	*Rhizosolenia minima*
Hemiselmis sp.	*Nitzschia longissima*
Plagioselmis prolonga	EUGLENOPHYCEAE
Teleaulax amphioxeia	*Euglena* sp.
Teleaulax acuta	*Eutreptiella* sp.
Teleaulax sp.	PRASINOPHYCEAE
DINOPHYCEAE	*Pedinomonas* sp.
Prorocentrum balticum	*Pseudoscourfieldia marina*
Katodinium rotundatum	*Pyramimonas* sp.
cf. *Oblea rotunda*	CHLOROPHYCEAE
Dinophysis acuminata	*Choricystis* sp.
CHRYSOPHYCEAE	*Kirchneriella* sp.
Uroglena sp.	*Monoraphidium contortum*
Pseudopedinella sp.	*Monoraphidium* sp.
Gonyaulax verior	*Crucugenia tetrapedia*
Apedinella spinifera	*Monoraphidium contortum*
PRYMNESIOPHYCEA	ZOOFLAGELLATA
Chrysochromulina sp.	*Telonema subtile*
	Ebria tripartita
	MESODINIUM
	Mesodinium rubrum

22.2.5. Benthic macrofauna

The macrofauna (= animals > 0,5 mm) of soft bottoms have been sampled for several decades for monitoring purposes as a means to detect the degree of pollution in the Finnish SW archipelago. Thus, long-time variations of species composition, abundance and biomasses are well known from most sea areas in the vicinity of Turku and Naantali. From the waters surrounding the harbour of Pargas the information on bottom macrofauna is scarcer.

In 1995 the Water Protection Association of SW FINLAND carried out an extensive benthic macrofauna survey in the inner parts of the Archipelago Sea. The sampling programme included 7 sampling stations in the port area of Turku and 6 in Naantali

(Fig. 1). In the port of Turku as well as in Naantali a total of 14 macrofauna species or groups were recorded (Tab. 3). The total abundance and biomass in the port of Turku were 413 - 1093 individuals per $m^2$and 19 - 164 g wet weight per m^2, respectively (Tab. 3). Corresponding values for Naantali were 446 - 1193 ind./m^2 and 51 - 430 g/m^2.

Table 3. Species composition of benthic macrofauna in the port area of Turku and Naantali (Räisänen 1997). For more information on abundance and biomass consult the list on http://www.abo.fi/fak/mnf/biol/www-sidor.html

NEMERTINEA:	INSECTA:
Prostoma obscurum	*Chironomus plumosus*
PRIAPULOIDEA	*Tanypodinae*.
Halicryptus spinulosus	MOLLUSCA, BIVALVIA:
ANNELIDA, OLIGOCHAETA:	*Macoma balthica*
Limnodrilus hoffmeisteri	*Cardium glaucum*
Potamothrix hammoniensis	*Mytilus edulis*
ANNELIDA, POLYCHAETA:	MOLLUSCA, GASTROPODA:
Harmothoe sarsi	*Potamopyrgus jenkinsi*
Marenzelleria viridis	*Hydrobia* sp.
Nereis diversicolor	
ARTHROPODA:	
Corophium volutator	
Neomysis integer	
Saduria entomon	
Monoporeia affinis	
Iaera sp.	

The dominating species of the benthic macrofauna communities in the harbours was the Baltic soft clam, *Macoma balthica*. It occurred on all stations and was the most important species when abundance as well as biomass is concerned (Tab. 3). The crustacean *Monoporeia affinis*, regarded as a clean water indicator species, showed high abundance on several stations in the port of Naantali, whereas it was absent in the port of Turku. In the strait west and east of the Turku harbour indicators of pollution such as oligochaete worms and red midge larvae (Chironomidae) were abundant. The occurrence of these taxa as well as other groups where used to estimate the degree of pollution of the areas according to the system of Leppäkoski (1975). The port area of Turku was considered semi-polluted with the exception of the straits west of the harbour which were classified as polluted. In the port of Naantali semi-polluted areas as well as semi-healthy ones were found. In both harbours there has been a change towards healthy zoobenthic communities since the 70s and 80s.

In the port area of Pargas only one bottom fauna sampling station has been repeatedly visited during the 90s (L. Paasivirta, unpubl.). Here oligochaete worms and chironomid larvae dominate the macrofauna, whereas the densities of *Macoma*, *Monoporeia* and polychaete worms tend to be low.

One of the most remarkable changes of the species composition of the bottom fauna observed in 1995 was the first records of the polychaete worm *Marenzelleria viridis*, which is thought to have been transported to the Baltic in ships' ballast tanks from north America in the early 80s. This species, known as one of the fastest dispersing non-indigenous species of the Baltic, was observed for the first time in Finland in 1990 in the western Gulf of Finland (Norkko *et al.* 1993). By now it has spread along the entire Finnish coast, including the Åland Islands, up to the S Bothnian Bay (Stigzelius *et al*. 1997). In 1995 it was already present on most sampling stations in the port areas of Turku and Naantali (Tab. 3) as well as in the intermediate archipelago zone off the towns.

Of the earlier introduced species in the Baltic, the New Zealand mud snail *Potamopyrgus antipodarum*, occurred in small numbers in 14 % and the N American soft shell clam *Mya arenaria* in 4 % of bottom samples in 1995 (Räisänen 1997). In the Archipelago Sea the sessile non-indigenous hydrozoan *Cordylophora caspia* and the barnacle *Balanus improvisus* are known to occur on firm substrates such as water vegetation, rocks, concrete surfaces and other hydrotechnical constructions. *B. improvisus* is abundant even on wooden poles in the low salinity water of the Aurajoki river, as known since 1868 (Luther 1950).

22.3. Traffic profile

Information on the ships' traffic of the three harbours was obtained from the Finnish Maritime Administration and to some extent from the local harbour authorities.

22.3.1. Foreign traffic

The port of Turku is Finland's second largest harbour when passenger and ro-ro traffic is considered. In 1996 ca 1300 harbour visits by the large passenger and car ferries on the Finland-Sweden line were registered (Appendix A) and almost 4 million passengers passed the port of Turku. During their voyage between Turku and Stockholm the ferries call at Mariehamn on the Åland Islands about every second time. Container carriers trading between Finland and Germany dominate the ro-ro traffic. In total about 200 ships visits from German North Sea harbours took place in 1996, the number of visits from German Baltic harbours being somewhat smaller. Ships from other countries, which visited Turku in 1996, were mainly European ones outside the Baltic region, e.g. Norway, Great Britain, Belgium and the Netherlands.

The number of foreign ships visiting the port of Naantali is considerably smaller than that of Turku (Appendix A). In 1996 the most numerous ship's visits were those by a passenger ferry on the Naantali-Mariehamn-Kapellskär (Sweden) line, which existed only for a few months in the summer. Since August 1996 there has been no regular ferry traffic between Naantali and Sweden. Apart from the ferries, the traffic to the port of Naantali is dominated by bulk carriers mainly from the Netherlands and Germany as well as tankers supplying the Naantali refinery with crude oil from Norwegian Atlantic harbours and Russian, Latvian and Estonian oil terminals in the Baltic. Also, large cargo vessels transporting coal from Poland to the Naantali power and heat plant account for a great part of the import to the harbour. The export is dominated by tankers transporting refined oil products mainly to Danish, Swedish and Estonian harbours.

The ships' traffic of the port of Pargas is almost entirely associated with the limestone quarry and industry of the town. The industry is supplied with limestone mainly by ships' traffic from the Gotland Island in the central part of the Baltic and plaster from Spain as well as coal from Russia. Limestone based products are exported to German harbours and a few other Baltic harbours. Pargas is a small harbour in terms of number of visiting ships and cargo volumes compared to Turku and Naantali.

22.3.2. Domestic traffic

The number of ships' visits from domestic harbours and the number of source ports and destination ports in 1996 are shown in the following table.

	Ships' visits	Source ports	Destination ports
Turku	285	7	3
Naantali	545	9	12
Pargas	139	3	12

The port of Naantali possesses the most intensive domestic traffic due to the transports of oil products along the entire Finnish coast from Hamina at the eastern Gulf of Finland to Tornio at the northernmost Gulf of Bothnia. The import to the port of Turku is dominated by transports of e.g. grain and sand from the archipelago off Turku. The export dominated traffic of the port of Pargas consists mainly of cement and other lime stone products being transported to harbours along the Finnish coasts, e.g. Kotka and Helsinki at the Gulf of Finland and Vaasa and Oulu at the Gulf of Bothnia.

22.3.3. Ballast water treatment

Exact information on ballast water discharges and loading in the harbour areas was not available since neither regional harbour offices nor the Finnish Maritime Administration register the volumes of ballast water that are pumped in or out in harbour waters by the ships. According to interviews with local harbour authorities in Turku, Naantali and Pargas, there is a general effort to make cargo vessels carry full load in both directions due to economic reasons. This will reduce the need of using ballast water and is especially true for the numerous ro-ro ships on the line between Turku and Germany. Ro-ro ships and passenger ferries posses the smallest ballast water capacity, whereas larger bulk carriers and tankers can carry ballast water volumes 12-75 times larger than those of ro-ro ships and passenger liners (Hayes & Hilliard 1996).

In the case of ballast discharge and loading, it takes place in the immediate vicinity of the harbours in most cases and seldom during the voyage along the ships' route through the archipelago. By regular dredging, the ships' routes are kept deep enough for most ships operating in the Baltic Sea, and therefore there is no need for them to reduce their draft by discharging ballast water before entering the Archipelago Sea.

According to information from harbour authorities in Turku at least some Finnish ships exchange their ballast water on the open sea, thus following the guidelines of IMO (1991).

Information on the amounts of imported and exported goods can give a hint of whether a harbour is a net donor or recipient of ballast water. According to Tab. 4 the import exceeds the export in Turku and Naantali, which suggests that visiting ships more often load ballast water than they discharge it in these harbours. In the port of Pargas the import from foreign harbours exceeds the export by 3 times, whereas the import of goods from domestic harbours is only a minor fraction of the export. This would mean that Pargas exports ballast to foreign harbours and imports it from harbours along the coast. The latter is confirmed by an interview with the captain of the ship carrying lime stone products from Pargas and returning ballasted from harbours along the whole coast of Finland. According to him the discharge of ballast water in the port of Pargas amounts to 1 500 - 2 700 m^3 per visit. Since about 100 visits are made each year the volume of ballast water released in this harbour would be 150 000 - 270 000 tons per year.

Table 4. Volumes (tons) of imported and exported goods in the ports of Turku, Naantali and Pargas in 1996. Data compiled from official statistics from the Finnish Maritime Administration.

	Import			**Export**			**Import/ export**		
Port	**Foreign harbour**	**Domestic harbour**	**Total**	**Foreign harbour**	**Domestic harbour**	**Total**	**Foreign harbour**	**Domestic harbour**	**Total**
Turku	1671126	271332	1942458	1512561	8465	1521026	1.10	32.05	1.28
Naantali	2814945	524485	3339430	706910	561663	1268573	3.98	0.93	2.63
Parainen	341375	58774	400149	113807	361740	475547	3.00	0.16	0.84

22.4. Risk profile

22.4.1. Transport distances, temperature and salinity

The introduction and establishment of a non-indigenous species (NIS) in a new region is depending on its ability to survive ships' transport in the ballast water or as a fouling organism on the hull, and its ability to survive and reproduce in the new environment. German studies on the occurrence of organisms in ballast tanks have shown that the number of individuals started to significantly decrease only after 40 - 50 days in ballast tanks (Gollasch 1996) This means that organisms transported in ballast water could survive the journey from most countries listed in Tab. 4 to the ports of SW Finland.

Although the volumes of ballast water transported into or from the ports of SW Finland are comparably small, this is no guarantee for alien species not to be spread in this way. Theoretically one single successful transport of viable NISs could be enough to introduce a species into a new region.

However, there are so far no reported human mediated introductions directly into Finnish waters. The occurrence of NISs in the coastal waters of Finland today is a result of secondary spread from other regions of the Baltic. The only exception might be the polychaete *Polydora redeki*, not known from sites between Kiel (SW Baltic) and Turku area when in was first recorded here in the mid-1960s (Leppäkoski 1984). One reason for the low number of alien species is the cold climate of the northern Baltic Sea. Warm water species adapted to temperatures ranging from about 12 to 30 °C (Fig. 3.) stand little or no chance to survive for longer periods in the Baltic. However, if the process of global warming goes on, the risks that warm water species get established in the Baltic Sea will increase. The seasonal temperature curves of the southern and northern Baltic are rather similar indicating that temperature is not a limiting factor for the establishment of species brought from the southern Baltic by ships to the harbours of SW Finland. Similarly, temperature is not limiting for the dispersal of organisms from the eastern Gulf of Finland to the Archipelago Sea.

Figure 3. Seasonal variation of surface water temperature in the Northern Baltic Sea (long-term average at the island of Seili ca 30 km south of Turku), southern Baltic Sea (long-term average at the Bornholm Sea) and a subtropic sea area (Gulf of Mexico in 1983). Data compiled from Haapala & Alenius (1994), Magaard & Rheinheimer (1974) and Levinton (1995).

Salinity is the other main factor that is crucial for the survival and reproduction of alien species in a new environment. Because of the low salinity of the Baltic few truly marine NISs have established themselves here and those present today are mainly brackish water species originating from estuaries. The salinity is, on the other hand, too high for the survival of most fresh water species. However, some euryhaline fresh water species, such as the zebra mussel *Dreissena polymorpha* and the cladoceran *Cercopagis pengoi* both originating from lakes and rivers in SE Europe, have in recent years been successful in colonising the lagoons of SE Baltic as well as the eastern Gulf of Finland, probably as a result of ballast water transports. According to the most recent reports in 1997 *Cercopagis* has spread all along the Finnish south coast the westernmost observations recorded from the Archipelago Sea off Turku Stockholm archipelago, (Gollasch 1996). Thus, it does not necessarily seem to need any human mediated vector for its westward dispersal.

In the case of the zebra mussel, the dispersal seems to have ceased in the region ca 100 km west of the Finnish-Russian border, where it was recorded for the first time in Finland in 1995 (Valovirta & Porkka 1996, I. Valovirta pers. comm). In 1997 it still occurred mainly on sheltered localities close to the open sea and was practically absent in the inner archipelago zone. As mentioned earlier there is regular ships' traffic between the harbours in the eastern Gulf of Finland and SW Finland, and at least the limestone carrying ship from Pargas often brings ballast water from the Gulf of Finland to the port of Pargas. If the ballast water intake occurs in the outer archipelago outside the ports in the eastern Gulf of Finland, where the density of *Dreissena* larvae is thought to be high at least temporarily, there is a risk that the larvae will be transported to other sea areas including the archipelago of SW Finland. Since temperature and salinity conditions in the outer archipelago of the eastern Gulf of Finland and the inner parts of the Archipelago Sea do not differ considerably, the zebra mussel can be considered a potential future human mediated invader from the east.

22.4.2. Local hot spots in the harbour areas

The low salinity in and just outside the mouth of the river Aurajoki makes this region a potential recipient of alien fresh water and brackish water species. In the harbour and along the river there are also a lot of firm surfaces that could serve as substrates for fouling organisms.

Another potential hot spot for the establishment of NISs are the industries of Naantali, where cooling water is taken in and released through pipelines. Sites with strong water currents and suitable temperature conditions have been shown to attract introduced species in many cases. *Balanus improvisus* has appeared to be abundant in eutrophicated harbour areas; in these waters the abundance is generally one or two orders of magnitude greater than the numbers in more natural environments (Vuorinen *et al.* 1986)

Also, the role of the port of Turku as a potential donor of pathogens cannot be ruled out, since the harbour area is directly susceptible to sewage water from two point sources, which periodically causes high densities of faecal bacteria in the harbour waters. According to the guidelines of IMO (1991) ballast loading is not recommended in waters where there is an obvious risk for intake of pathogens.

22.4.3. Economical and environmental consequences of the introduction of alien fouling organisms

Of the NISs occurring in coastal waters of SW Finland today, two fouling organisms, *Balanus improvisus* and *Cordylophora caspia*, are causing economical costs to shipping, boating and fish farming, as well as industries and power plants where cooling water from the sea is used. *Balanus* occurs commonly as a fouling organism in power plants between the towns Vaasa (Gulf of Bothnia; 63 N) and Kotka (Gulf of Finland; 27

E) whereas *Cordylophora*, which is a genuine brackish-water species, occurs along the whole Finnish coast (Vuorinen *et al.* 1986).

Besides mechanical cleaning of surfaces covered with *Balanus* and *Cordylophora*, antifouling paints have been used largely on the hulls of boats and ships and to some extent on the cages of fish farms and in cooling water pipelines. The use of antifouling paints amounted to about 130 000 l in 1987 in the whole country (Ylä-Mononen 1989) and about one third of this volume was used on the hulls of smaller pleasure boats.

The use of anti-fouling paints is connected with leakage into the water of heavy metals and other substances acting as active compounds in the paints. Seaweeds, such as brown and green algae, have been shown to accumulate heavy metal ions from the water. Antifouling paints containing Hg, As, Cd and PCB were used until the 70s, thus contributing to the contamination of the water environment. The use of these paints was forbidden in the 70s in Finland, and since 1991 there is a prohibition against the use of Sn-containing paints on the hulls of boats with a length less than 25 m. The active compound of the paints used on smaller boats today is mostly Cu, whereas Sn is still used on ships' hulls.

22.5. References

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APPENDIX A.

Ships' traffic (foreign harbours) of the ports of Turku, Naantali and Pargas in 1996. Data compiled from official statistics from the Finnish Maritime Administration.

PORT OF TURKU

Import				Export			
Country	No. of ships	DWT	Mean DWT	Country	No. of ships	DWT	Mean DWT
Sweden, Baltic Sea ports	1305	4261283	3265	Sweden, Baltic Sea ports	1299	3434896	2644
Germany, North Sea Ports	233	994943	4270	Germany, North Sea Ports	199	1960078	9850
Germany, Baltic Sea ports	157	1558695	9928	Germany, Baltic Sea ports	106	548674	5176
Norway	87	305215	3508	Norway	92	234045	2544
Great Britain	65	418680	6441	Great Britain	63	406469	6452
Belgium	57	639055	11211	Netherlands	31	95074	3067
Netherlands	44	214023	4864	France	15	44358	2957
Poland	37	162476	4391	Spain	9	41398	4600
Estonia	16	93651	5853	Belgium	8	25774	3222
Iceland	6	6762	1127	India	6	62383	10397
Spain	6	14025	2338	Taiwan	5	52555	10511
Denmark	5	10299	2060	Poland	4	16312	4078
Russia, Kaliningrad	4	2244	561	Portugal	3	5064	1688
Sweden, Bothnian Sea ports	2	7555	3778	Italy	3	11005	3668
France	2	15141	7571	Greece	3	11850	3950
Latvia	2	6297	3149	South Korea	3	35120	11707
Russia, St. Petersburg	1	3043	3043	Iceland	2	7920	3960
Portugal	1	2625	2625	Pakistan	2	15567	7784
Italy	1	5735	5735	Indonesia	2	14850	7425
Bulgaria	1	2422	2422	Vietnam	2	9343	4672
Japan	1	12800	12800	Philippines	2	17375	8688
Tot.	2033	8736969	4298	Antilles	2	9356	4678
				Sweden, Bothnian Sea ports	1	2287	2287

Estonia	1	8143	8143
Denmark	1	1212	1212
Ireland	1	2360	2360
Turkey	1	4302	4302
Egypt	1	9595	9595
Morocco	1	5735	5735
Guinea	1	10996	10996
Singapore	1	9595	9595
Thailand	1	9682	9682
China	1	5200	5200
Japan	1	9650	9650
USA	1	3959	3959
El Salvador	1	5397	5397
Antigua & Barbuda	1	5397	5397
Guyana	1	3959	3959
Brazil	1	3590	3590
Papua New Guinea	1	12760	12760
Tot.	1879	7173285	3818

PORT OF NAANTALI

Import			
Country	No. of ships	DWT	Mean DWT
Sweden, Baltic Sea ports	61	219799	3603
Netherlands	47	238888	5083
Russia, Kaliningrad	36	244744	6798
Estonia	32	170310	5322
Germany, Baltic Sea ports	28	170690	6096
France	20	43723	2186
Poland	18	364952	20275
Norway	17	844978	49705
Lithuania	16	62381	3899
Denmark	16	165545	10347
Belgium	13	43872	3375
Latvia	11	623530	56685
Great Britain	11	27234	2476
Germany, North Sea ports	10	21078	2108
Sweden, W coast ports	7	17773	2539
Russia, St. Petersburg	7	75398	10771
Spain	6	16323	2720.5
USA	4	96463	24116
Italy	3	15506	5169
Sweden, Bothnian Sea ports	3	2935	978
Iceland	2	2723	1362
Ireland	2	3288	1644
Tunisia	1	4471	4471
Philippines	1	1720	1720
Canada	1	14550	14550
Venezuela	1	91263	91263
Tot.	374	3584137	9583

Export			
Country	No. of ships	DWT	Mean DWT
Sweden, Baltic Sea ports	86	295462	3436
Denmark	44	146551	3331
Sweden, W coast ports	40	135900	3398
Estonia	22	125824	5719
Norway	22	81738	3715
Latvia	18	198379	11021
Great Britain	13	12535	964
Sweden, Bothnian Sea ports	11	104781	9526
Poland	10	46178	4618
Germany, North Sea ports	9	44834	4982
Italy	9	67473	7497
Netherlands	8	93749	11719
Belgium	6	56566	9428
Venezuela	4	55100	13775
Germany, Baltic Sea ports	3	8045	2682
Spain	3	17955	5985
Croatia	1	2180	2180
Saudi-Arabia	1	52670	52670
Tot.	310	1545920	4987

PORT OF PARGAS

Import			
Country	No. of ships	DWT	Mean DWT
Sweden, Baltic Sea ports	35	2940	84
Spain	7	44208	6315
Denmark	6	26677	4446
Netherlands	6	10773	1796
Russia, St. Petersburg	4	38657	9664
Sweden, W coast ports	3	10780	3593
Estonia	3	6331	2110
Sweden, Bothnian Sea ports	2	134508	67254
Norway	2	4300	2150
Poland	1	0	0
Tot.	69	279174	4046

Export			
Country	No. of ships	DWT	Mean DWT
Germany, Baltic Sea ports	17	79300	4665
Sweden, Baltic Sea ports	6	6381	1064
Latvia	4	6854	1714
Estonia	3	3855	1285
Russia, Kaliningrad	1	3159	3159
Lithuania	1	1706	1706
Tot.	32	101255	3164

23. The St. Petersburg Harbour Profile

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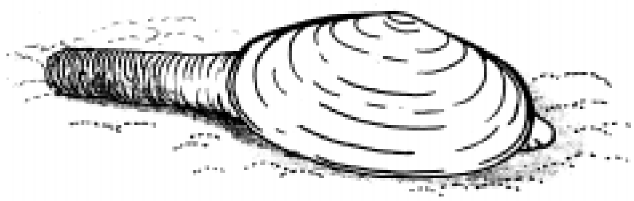
23.1. Introduction

St. Petersburg is the largest cities in the Baltic region with five million inhabitants. St. Petersburg has a strategic position in the Baltic Sea, located at the lower Neva River, at the intersection of main transoceanic (from Atlantic Ocean) and transcontinental (from the basins of White, Black and Caspian seas) shipping routes (Fig.1).



Mya arenaria, the soft-shell clam

Fig.1.Traffic routes (dashed line) from the White (1), and Ponto-Caspian (2) basins via St. Petersburg (asterisk).

St. Petersburg Sea Port area is the destination for a number of ships, both domestic and foreign (Fig 1). Until recently, the alien species introductions associated with the shipping activity have not been considered a problem by the St. Petersburg authorities, despite the increasing number of exotic species introductions in the area. Baikalian amphipod, *Gmelinoides fasciatus*, zebra mussel *Dreissena polymorpha* and predatory cladoceran *Cercopagis pengoi* (the latter two are the Ponto-Caspian species) are among the most recent and the most potentially harmful invaders in the Neva Estuary (Alimov 1997, Alimov *et al.* 1998, Panov *et al.* 1997). St. Petersburg region is also an important donor area of alien species for other countries worldwide. For example, St. Petersburg Port area was suggested as a source of the recent invasion of the Palearctic predatory cladoceran *Bythotrephes cederstroemi* (spiny waterflea) to the North American Great Lakes (Sprules *et al.* 1990). A recent genetic study of *B. cederstroemi* confirmed the existence of the Lake Ladoga - Baltic Sea invasion corridor (Berg *et al.* 1998). *B. cederstroemi* is a common species in pelagic communities of Lake Ladoga and upper Neva Estuary. In the latter location, adjacent to the St. Petersburg Port, it has coexisted since 1995 with the exotic species of spiny waterflea, *Cercopagis pengoi* (see section 4.2 for details). Examples on disastrous consequences of alien species introductions from other aquatic ecosystems, along with first data on economic losses for local fishery due to *C. pengoi* biofouling of fishing equipment in the Neva Estuary, might enforce local authorities to acknowledge the problem and take it into account in decision-making (Alimov *et al.* 1998). In late 1998, a first step was taken when the Special Inspection for Sea Protection started to collect and analyse available data on ballast water and ship traffic in the St. Petersburg area.

23.2. The harbour environmental profile

23.2.1. Location

The St. Petersburg Sea Port is located in the south-eastern part of the Neva River delta, and the actual harbour area occupies approximately 500 km^2 of the Neva Estuary. This is where the approaching ships, prior to entering the port via a shipping channel, usually have to wait for the pilot and port service in the special designated zone ("the pilot meeting site") located almost 50 km to the west from St. Petersburg (Fig. 2). In some cases ballast water is taken or released in this designated area. Thus, a significant part of the Neva Estuary is affected by the intensive ship traffic. The Neva River, a connecting channel between the Lake Ladoga and the Gulf of Finland, is the major tributary to the Baltic Sea. The Neva Estuary consists of the upper freshwater part, shallow Neva Bay (mean depth 4 m), and lower brackish water part (mean depth in offshore areas 20-30 m), which includes large areas of the eastern Gulf of Finland (EGF).

23.2.2. Salinity

Water in the St. Petersburg Sea Port area and Neva Bay is completely fresh, with the conductivity at all depths ranging between 0.13-0.24 mS/cm at 25 ^oC (0.06-0.11 ppt) (Alimov 1997). In the outer estuary, the surface water is more saline, reaching 3.6 ppt in summer. During spring and summer the outer estuary is characterised by strong vertical gradients in the salinity, with mean values of 1-2 ppt at the surface, 4-5 ppt at 20 m, and >7 ppt at depths >50 m (Mikhailov 1997). Surface water salinity in the Neva Estuary gradually increases towards the open Gulf of Finland up to 6.5 ppt (Shishkin *et al.* 1989, Mikhailov 1997) (Fig. 3). Water of the Neva River significantly affects the seasonal and annual variations in the surface water salinity in the estuary. During ice-cover period, from December through March, the surface salinity in the lower estuary (Ozerki Hydrometeorological Station, Fig. 3) decreases from 2.2 ppt to 0.3 ppt, as a result of decrease in the Neva River discharge and absence of water mixing. During April - May surface water salinity increases 5-6 fold, from 0.3 ppt to 1.5-1.8 ppt, and then gradually increases during summer months up to a maximum of 2.2 ppt in autumn (Myakisheva 1996). Thickness of the surface layer with significant seasonal changes in salinity does not exceed 5-10 m (Mikhailov 1997).

Figure 2. Map of the St. Petersburg Harbour area. Arrows indicate the storm-surge barrier. Filled asterisk indicates the pilot meeting site, open asterisk indicates the St. Petersburg Sea Port. Dashed line indicates ships route.

Figure 3. Schematic map of the Lake Ladoga – Neva River – EGF water system. Numbers indicate the surface water salinity. Filled asterisk indicates the Ozerki Hydrometeorological Station, open asterisk in filled circle indicates the Leningrad Nuclear Power Plant.

23.2.3. Temperature

Development of ice cover every winter is a characteristic feature of the easternmost Gulf of Finland (Drabkin 1997). In the Gulf of Finland hardness of ice conditions rapidly increases from the west to the east because of a decrease in depth and salinity. Ice first appears in the easternmost Gulf in late November - early December, and then ice-break occurs in early May (Drabkin 1997). During January - March water temperature is close to 0 ^{o}C, and temperature rapidly increases after the ice-break in April-May, usually reaching 3 ^{o}C in late April, and 10 ^{o}C in May (Mikhailov 1997). Summer temperatures of 18-20 ^{o}C occur in late July - early August, with the absolute maximum up to 24-26 ^{o}C. Temperature drops below 10 ^{o}C in the period between September 20th and October 5th, and below 5 ^{o}C in late October. Intensive solar radiation and low wind activity during the summer period result in development of seasonal thermocline with vertical temperature gradients up to 2.5 ^{o}C/m (Mikhailov 1997). Local warm water discharges affect temperature and ice regime in some areas, especially in Koporskaya Bay, influenced by warm waters from the Leningrad Nuclear Power Plant.

23.2.4. Trophic status of the harbour waters

The Neva Estuary is a heavily loaded area. Water quality in the estuary is influenced by a number of factors such as: 1) water quality in Lake Ladoga; 2) anthropogenic load to the upper Neva River; 3) waste water discharges from St. Petersburg and its environs; 4) natural processes in the water body; 5) impact of construction of hydraulic systems which would protect the city from floods (Skakalski 1997). At present, almost 60 % of the nitrogen load of the EGF comes with the Neva River waters from Lake Ladoga and the Neva tributaries, and is considered as a natural source of nitrogen (Savchuk & Skakalski 1997). Unlike nitrogen, more than 50 % of phosphorus is retained in the Neva Bay ecosystem, mainly due to its utilisation by autotrophs (Gutelmakher & Umnov 1987) and because of physical and chemical adsorption processes (Carman 1990). Maximum concentration of total phosphorus in the Neva Bay during spring and summer is around 60 μg/l, in average at about 10 μg/l in surface waters and 4.0-5.5 μg/l near bottom (Shpaer 1997). In the EGF, accumulation of phosphorus in water prevails over its utilisation during the process of photosynthesis. Maximum concentration of phosphorus in the surface waters of the EGF, according to the 1986-1992 data, can reach 60 μg/l (average between 10-25 μg/l), while near the bottom its concentration may be either very low (0.4-4.5 μg/l), or up to 80 μg/l, depending on the season (Shpaer 1997). The estimates of total anthropogenic load on Neva River, Neva Bay and EGF are given in Tab. 1.

Table 1. Estimates of anthropogenic load (tons/year) on the ecosystems of Neva River, Neva Bay and EGF (after Savchuk & Skakalski 1997). Asterisk (*) indicates BOD_5.

Water body	**Source of pollution**	**BOD_{tot}**	**Total nitrogen**	**Total phosphorus**
Neva River	Waste discharges from industries, farms and municipalities	17000	4970	320
Neva Bay	“	14000	24000	2500
Eastern Gulf of Finland	Outflow of dissolved matter from Neva Bay	127000*	70000	1500

During summer, the concentration of total nitrogen in the Neva Bay decreases, but its transport from the bay to the EGF increases due to general seasonal increase of the Neva River water discharge. On the other hand, decrease of the total phosphorus concentration in the Neva Bay during summer is so significant that it results in phosphorus losses which cannot be compensated neither by anthropogenic load on the Neva Bay, nor by phosphorus inflow with the Lake Ladoga waters (Savchuk & Skakalski 1997).

Chlorophyll-a concentrations in the Neva Bay are usually lowest in the north-eastern part (2.07 μg/l) and highest in the southern part (19.71 μg/l), averaging at 9.74±5.18 μg/l for the whole Neva Bay. In the EGF, chlorophyll-a concentrations varied between 5.29-14.69 g/l, averaging at 10.57±1.66 μg/l in the shallow area and exposing lower values in the deeper waters: 5.40±0.10 μg/l (Telesh *et al.* in press).

In summer, Secchi depth is minimal in the south Neva Bay (1-1.2 m), intermediate in the eastern and central Bay (1.5-2m), and highest in the lower Neva Estuary (2-3 m) (values for August 1997, after Alimov 1997).

23.2.5. Phytoplankton, zooplankton and zoobenthos

At present, the summer phytoplankton in the Neva Bay is generally dominated by Cryptophytae (34 % of total biomass) and diatom algae (32 %). Green algae contribute 16 % and blue-greens only 12 % to the phytoplankton biomass, which vary between 0.2-1.94 mg/l and average at 1.07 mg/l in the Neva Bay (Telesh *et al.*, in press). In the EGF, the blue-greens, mainly *Planktothrix agardhii*, strongly dominates the phytoplankton community contributing in average 78.3 % to the total algal biomass. Two species of the Cryptophyta: *Cryptomonas erosae* and *Chroomonas acutae*, are now newly included in the list of dominants. At present, these two species constitute about 18% of total phytoplankton biomass in the whole water system from Lake Ladoga down to the Gulf of Finland. Mean total phytoplankton biomass in the EGF averages at 4.36±1.23 mg/l, which is almost 4 times higher than in the Neva Bay (1.14±0.68 mg/l).

The summer zooplankton in the Neva Bay is numerically dominated by rotifers (in average, 86 % of total zooplankton density and 84 % of total biomass), with a comparatively high abundance of juvenile stages of copepods, mainly cyclopoids *Mesocyclops leuckarti*. However, the community structure of zooplankton is different in various zones of the estuary. Among rotifers, a facultative predatory species *Asplanchna* *priodonta* is playing an important role in the pelagic community, especially in the southern part of the Neva Bay. Other dominant zooplanktonic species in the Neva Bay are the rotifers *Synchaeta stylata* and *Conochilus unicornis*. Total zooplankton numbers in the Neva Bay in August 1996 averaged at 66.5 ind./l (range 4.7-233.4 ind./l), mean biomass was 0.42 mg/l (range 0.02-1.65 mg/l).

Data on plankton abundance indicates the formation of zones with high water retention efficiency in the SW and NW areas of the Neva Bay where planktonic organisms exposed highest population densities and biomasses: 1.94 and 1.65 mg/l for phyto- and zooplankton, respectively.

In the shallow waters of the EGF cyclopoid copepods, mainly *M. leuckarti*, generally dominate the zooplankton communities. Total zooplankton density and biomass vary between 32-134 ind./l (mean 72.2 ind./l) and 0.29-1.13 mg/l (mean 0.71 mg/l). In average, rotifers contribute 15.5 % to the total zooplankton biomass in the EGF, cladocerans 14.4 %, copepods 70.3 %. Among cladocerans, predatory forms (*Bythotrephes*, *Cercopagis* and *Leptodora*) are relatively abundant in the EGF.

Oligochaeta is a dominating group both in abundance and biomass of the bottom communities of macrozoobenthos in most parts of the Neva Bay, as well as in the EGF. Large Unionidae contribute significantly to the macrozoobenthos biomass in western Neva Bay, whereas small filtering Pisidiidae are important in some eastern communities of the bay that were influenced by the Neva River. In August 1996 highest biomasses of macrozoobenthos were registered in the NW (127 g/m^2) and SW (134 g/m^2) areas of the bay. Benthic communities of the EGF were comprised mainly by Oligochaeta and Chironomidae, both groups together accounted for more than 95 % of total community abundance and biomass, the latter ranging from 12 to 46 g/m^2. List of nonindigenous species (NIS) is presented in Tab. 2.

Table 2. Nonindigenous species (NIS) in the Neva Estuary.

SPECIES	DISTRIBUTION	AREA OF ORIGIN	REFERENCES
Cnidaria			
Cordylophora caspia	Koporskaya Bay	Ponto-Caspian	Alimov *et al*. 1998
Annelida/Polychaeta			
Marenzelleria viridis	Koporskaya Bay	North America	Lyakhin *et al.* 1997
Annelida/Oligochaeta			
Potamothrix vejdovskyi	Neva Bay	Ponto-Caspian	Panov *et al.* 1997
P. heukeri	Neva Bay, lower Estuary	Ponto-Caspian	Panov *et al.* 1997
Paranais frici	lower Estuary	Ponto-Caspian	Panov *et al.* 1997
Mollusca			
Dreissena polymorpha	lower Estuary	Ponto-Caspian	Panov *et al.* 1997
Potamopyrgus antipodarum	lower Estuary	New Zealand	Alimov 1997
Arthropoda/Crustacea			
Acartia tonsa	lower Estuary	North America	Silina 1997
Cercopagis pengoi	lower Estuary	Ponto-Caspian	Bychenkov & Rodionova 1996, Panov *et al*. 1996
Balanus improvisus	lower Estuary	America	Alimov *et al.* 1998
Gmelinoides fasciatus	Neva Bay	Siberian	Alimov 1997
Eriocheir sinensis	lower Estuary	SE Asia	Alimov *et al.* 1998
Fish			
Acipenser ruthenus	Lake Ladoga, Neva River, eastern Gulf of Finland	Ponto-Caspian	Kudersky 1996
A. baeri		Central Asia	
A. gueldenstaedti		Ponto-Caspian	
Oncorhynchus mykiss		North America	
Coregonus autumnalis		Siberia	
C. nasus		Siberia	
C. muksun		Siberia	
C. peled		Siberia	
Catostomus catostomus		Siberia	
Perccottus glenii		Far East of Russia	
Cyprinus carpio		East Asia	

23.3. The harbour traffic profile

According to the St. Petersburg Pilot Service (unpubl.), ship traffic from the Ponto-Caspian basin amounts to 1000 ships/year (mean DWT 3000) at present. Tankers comprise about 50 % of the traffic (mean DWT 2000-3000). The role of the traffic from the White Sea is negligible, not more than 2-3 ships/year (mean DWT 2000-5000).

23.4. The risk profile

23.4.1. Introduction

As many other estuaries of big rivers, the easternmost part of the Gulf of Finland where St. Petersburg harbour is located, provides a large variety of habitats for benthic, planktonic and nektonic organisms. Due to the salinity gradient, freshwater and brackish water species often coexist in this area. Differences in depth, temperature and hydrological regime between the various parts of the EGF are other factors that do not only support the diversity of native species but also facilitate the establishment of populations of alien organisms.

There are several non-indigenous species (NIS) that have already successfully invaded the harbour area (Tab. 2). However, as stated above, contamination by alien species has not been considered an environmental problem by the local water authorities until recently (Alimov *et al.* 1998). Nothing has been done to prevent the invasions or to evaluate the risk of new introductions. It is quite clear that the establishment of some exotic species may have severe impacts on commercial fishery, water quality, etc. However, at present it is difficult to assess the real and/or potential economical losses due to NIS invasions on a quantitative basis (except the *C. pengoi* case: see next section).

It is equally difficult to forecast "the emigration and immigration policy" in respect to particular species in the EGF. Besides common problems resulting from the low predictive capability of the theory of ecological invasions (Kornberg & Williamson 1986, Kareiva 1996), we lack the complete data on the invasion history and biology of NIS in (and around) the EGF. Here we outline some of the " hot spots" which seem to be important for invasion risk assessment; however, further research is required to make its basis more substantial.

23.4.2. *Cercopagis* vs. *Bythotrephes*: a case study of predatory cladocerans

The transfer of the Palearctic predatory planktonic cladoceran *Bythotrephes cederstroemi* from the St. Petersburg Harbour area to the Lawrentian Great Lakes and the invasion of EGF by the Caspian predatory cladoceran *Cercopagis pengo*i are probably the two most striking events in the recent invasion history of the harbour area. Both *B. cederstroemi* and *C. pengo*i belong to the family Cercopagidae (Crustacea: Onychopoda).

Bythotrephes, a native species to Lake Ladoga and upper Neva Estuary, invaded the St. Lawrence Great Lakes with ballast waters of ships returning from the Leningrad (St. Petersburg) Port in early 1980s, as suggested by Sprules *et al.* (1990). Recently this hypothesis has been supported by the genetic study of *Bythotrephes*, confirming the existence of the Lake Ladoga – Baltic Sea invasion corridor (Berg *et al.* 1998). This invasion proves that there is a possibility of transoceanic transfer of relatively large planktonic organisms from the St. Petersburg area. A significant part of the *Bythotrepes* population in the EGF is represented by individuals, which are morphologically different from the individuals from both Lake Ladoga and the Great Lakes populations (*Bythotrephes longimanus* type). The "Lake Ladoga type" of *Bythotrephes* (*B. cederstroemi*) is often present in the estuary, and there is some additional evidence of a polyclonal structure of *Bythotrephes* population in the EGF (P. I. Krylov unpubl.). Thus, this case illustrates the potential importance of individual (or clonal) characteristics of transferred specimens in determining the success of invasion.

The invasion history of the Ponto-Caspian predatory cladoceran *Cercopagis pengoi* is even more remarkable. *C. pengoi* is native to the Caspian, Aral and Azov seas and the Black Sea estuaries, and is known to be able to spread from its native habitats to freshwater reservoirs of the Volga and Don basins (Mordukhai-Boltovskoi & Galinski 1974, Mordukhai-Boltovskoi & Rivier 1987). In 1992 *C. pengoi* was found in the Baltic Sea area, a likely result of the discharge of ballast water (Ojaveer & Lumberg 1995). In the same year, it was found in the pelagic part of Gulf of Finland (A. Laine pers.comm.). In 1995 *C. pengoi* was registered in coastal Finnish waters as a biofouler of fishing nets (Kivi 1995). In the upper Neva Estuary *C. pengoi* was first found in 1995 (Bychenkov & Rodionova 1996, Avinski 1997). Since then *C. pengoi* has become an abundant zooplankton species in the Neva Estuary (Panov *et al.* 1996, Krylov *et al.* 1998), and its development in the upper Neva Estuary has corresponded with a drastic decline in the abundance of *Bythotrephes* (Panov *et al.* 1998).

The *C. pengoi* population established in the Neva Estuary, showed a remarkable reproductive strategy, producing a large number of resting eggs during summer months (Panov *et al.* 1996, Krylov & Panov 1998). It has been suggested that this large pool of resting eggs in the Neva Estuary population has enabled *C. pengoi* to achieve fast population growth in new environments, and an increasing risk of *C. pengoi* being dispersed by ships' ballast water (Panov *et al.* 1996, Panov *et al.* 1997). *C. pengoi* has not been among the species of Ponto-Caspian fauna predicted to invade the Great Lakes - St. Lawrence River system (Ricciardi & Rasmussen 1998). However, in summer 1998 *C. pengoi* was found in Lake Ontario, snagged on sport fishing lines (MacIsaak *et al.* 1999). Most likely this is a question of secondary introduction from the eastern Baltic via an existing invasion corridor. The invasion of *C. pengoi* to the Lawrentian Great Lakes demonstrates the limited effectiveness of ballast water exchange programmes in preventing introductions of aquatic invertebrates producing resting eggs, which may accumulate in sediments of ballast tanks.

The recent invasion of EGF by *C. pengoi* may have the most important consequences from the economical point of view. Similarly to Finland, *C. pengoi* was noted to form a paste, filling fishing nets and trawls in the harbour area. Economical losses in the fishery farm Primorsky Ribak, located at the northern shore of the lower Neva Estuary, averaged in 1996 - 1998 at minimum 50 000 USD. These losses were connected to the drastic decline in the fish catches in the coastal zone of EGF due to biofouling of fishing equipment (Table 3). If the density of *Cercopagis* will not decrease significantly in the nearest future, it may seriously affect the commercial fishery in the area.

Table 3. Catches of common bream (metric tonnes) in the Primorsk (Koivisto) area in 1992-1998.

Year	1992	1993	1994	1995	1996	1997	1998
Catch	29.9	35.7	32.2	32.4	24.0	22.4	10.3

Apart from estimations on economic impacts, the analysis of *C. pengoi* invasion may contribute to the theory of ecological invasions. The success of a particular introduction is often discussed in terms of presence or absence of vacant niches (e.g. Herbold & Moyle 1986). At the time of the invasion, the niche of large planktonic invertebrate predators in the EGF community had a large number of native species including *Leptodora, Bythotrephes*, and mysids. In general, it was difficult to predict the appearance of one more species with similar feeding requirements. However, the establishment of the *C. pengoi* population was successful. Future research is needed to provide insights into ecological interactions within the planktonic community of the EGF.

23.4.3. The occurrence of potential habitats: Koporskaya Bay

Koporskaya Bay receives thermal discharges from the nuclear power plant and is literally a "hot spot" near the harbour area. The thermal discharges considerably affect the life of the native organisms (e.g. Krylov 1978, Ryabova & Krylov 1988) and provide conditions for establishment of NIS populations. There are several examples of NIS in the EGF which are restricted to, or most abundant, in Koporskaya Bay (*Cordylophora caspia, Marenzelleria viridis, Potamopyrgus antipodarum*). Koporskaya Bay area already serves as a permanent "thermal refuge" for NIS of southern origin, and there is little doubt that their number and the role in planktonic or benthic communities will increase in the future. Not only are these species a risk for the functioning of the power plant (e.g. via biofouling of water supply and cooling systems), they may spread to other parts of the EGF, including the harbour area, especially in warm years. In that case the risk of their further dispersal by ships (in ballast water and/or in biofouling communities) also increases.

23.4.4. Potential sources of invasions: Ponto-Caspian basin

As a significant part of the ship traffic to St. Petersburg Harbour come from the Ponto-Caspian basin, it may be considered the most important source of potential invaders of the EGF and the Baltic Sea in general.

Most (if not all) NIS that are known to inhabit the waters near the St. Petersburg Harbour have previously been reported from the areas outside their original distribution. In other words, only the species that had already demonstrated their ability to spread are now established alien species in the Neva Estuary. This fact decreases the number of potential invaders, however, this number is still too large to make predictions for particular species.

Two different groups of Black and Caspian Sea inhabitants are of main concern for invasion ecology. The first group consists of the native Ponto-Caspian species that are known to extend the boundaries of their initial distribution. The second group consists of the exotic species that have invaded these seas and can be expected to continue dispersing in novel environments. Both groups include dozens of species of almost all taxa (Mordukhai-Boltovskoi 1960, 1979, Valkanov *et al.* 1978), too numerous to be listed here. Thus, only few examples will be referred to in this paper.

The dramatic results of the invasion of the Black and the Azov seas by the ctenophore *Mnemiopsis leidyi* are well documented (Vinogradov *et al.* 1989, Volovik *et al.* 1996, GESAMP 1997). It has been feared that it may reach the Baltic Sea (Anon. 1994), although its temperature preferences are very different from those provided by the Baltic environment. Besides *M. leidyi*, there are many other newcomers to the Ponto-Azov basin; two recent examples are *Scapharca cornea* (Mollusca: Bivalvia) and *Doridella obscura* (Mollusca: Prosobranchia) (Sinegub 1993, Getmanenko 1996). However, special research is required to assess the probability of their further dispersal to new habitats.

There are also many native Ponto-Caspian species that have extended their distribution outside initial boundaries. Some of them will be listed in the next section.

23.4.5. Black Sea - Baltic Sea invasion corridor

The system of rivers, canals and reservoirs which connects the water bodies of the Caspian, Black and Baltic Sea serves as an important invasion corridor enabling or facilitating species dispersal in the meridianal direction. Besides being a shipping route, this system provides a variety of habitats where the species from the Black and Caspian seas may settle on their way to the north (as well as for the northern species in opposite direction). The number of species moving northwards is significantly higher than those moving southwards (Dzyuban 1962, Mordukhai-Boltovskoi & Dzyuban 1976, Pidgayko 1976).

Besides *C. pengoi*, two other Caspian cladocerans, *Cornigerius maeoticus* and *Podonevadne trigona* subsp. *ovum*, and two copepods, *Heterocope caspia* and *Calanipeda aquaedulcis* (Fig. 4), have extended their distribution to the reservoirs of Don, Dnieper and Volga rivers (Mordukhai-Boltovskoi 1965, Mordukhai-Boltovskoi & Galinski 1974, Vol'vich 1978, Gusynskaya & Zhdanova 1978), demonstrating their ability to establish permanent populations in freshwater. This ability increases the risk of their further dispersal, the chances of these four species arriving to the EGF in the future seem to be high.

Figure 4. Planktonic crustaceans from the Caspian Sea which have invaded the reservoirs of Don, Dnieper and Volga Rivers. **A**: *Cornigerius maeoticus* Pengo (females); **B**: *Podonevadne trigona* subsp. *Ovum* (Zernov) (females); **C**: *Calanipeda aquaedulcis* Kritschagin; **D**: *Heterocope caspia* Sars (female); **E**: *H. caspia* (male). Redrawn from Mordukhai-Boltovskoi, 1965 (**A, B**) and Borutskiy et al., 1991 (**C, D, E**)

Stepwise establishment of NIS populations in the water bodies along the invasion corridor allow adapting their life cycles to the new environment and, thus, increases the risk of their dispersal further north. There are many examples of invasions by the Ponto-Caspian species of the reservoirs of lower Don, Dnieper and Volga rivers (Mordukhai-Boltovskoi 1965, 1979, Zhuravel' 1969, Borodich 1976). However, the communities of the reservoirs in the northern part of this system also host a large (and quickly growing) number of exotic species. *Actinocyclus variabilis, Hypania invalida, Gmelinoides fasciatus, Dikerogammarus* sp., *Archaeobdella esmondi, Neogobius melanostomus, N. kessleri, Clupeonella cultriventris* and several other species of plants and animals are now permanent members of the communities of the reservoirs of the upper Volga River (Kopylov 1996). From these reservoirs they spread to other neighbouring lakes and rivers. For example, four Ponto-Caspian species (*Astacus leptodactylus, Dikerogammarus haemobaphes, Dreissena polymorpha* and a polychaete *Hypania invalida*) were recently found in Moscow River inside the boundaries of the Moscow City (L'vova *et al.* 1996).

Several lakes and reservoirs along the shipping route from the Black and Caspian Seas to the Baltic Sea receive thermal discharges from power plants. Like Koporskaya Bay, they may serve as "thermal refuges" for exotic species of southern origin. In warm years these non-indigenous species may spread to other water bodies. To illustrate this thesis, we provide an example derived from the results of zooplankton survey of the Ivan'kovo Reservoir that is affected by wastewater's of the Konakovo Power Plant. A southern cladoceran species, *Moina brachiata*, was first found in the heated area of Ivan'kovo Reservoir in June 1973. Later in the season it had spread over the other parts of the reservoir, and the next season (1974) it was found in the neighbouring Rybinsk Reservoir (Stolbunova *et al.* 1975, Mordukhai-Boltovskoi *et al.* 1975).

23.4.6. Other potential sources of invasions

The other major source of potential invaders of the EFG are the species of different origin (including Baikalian endemics) that were intensively introduced to the lakes and rivers of North West Russia to improve fish food resources. Some of them have already penetrated the communities of the harbour area. The most recent example is the Baikalian amphipod *Gmelinoides fasciatus* (Table 2), which was intentionally introduced in 1970s in the Karelian Isthmus lakes, later spread to the Lake Ladoga (Panov 1996, Panov *et al.* 1996) and to the Neva Bay, St. Petersburg Harbour area (Alimov 1997, Alimov *et al.* 1998), where it replaced the native amphipod *Gammarus lacustris* (V.E. Panov unpubl.). Unintentional release of exotic aquatic organisms should also be considered as a potentially important source of NIS, considering the proximity of the second largest city in Russia. The establishment of the Amur sleeper *Perccottus glenii* in the EGF basin is an example of a successful introduction as a result of an aquarium fish release. The Amur sleeper has a high potential to significantly decrease the native fish diversity and abundance in freshwaters (Shatunovski 1998, Pronin *et al.* 1998). Information is generally lacking on present distribution and impacts of intentionally introduced or released alien species. Special efforts are needed to assess the risk of alien species introductions from these sources.

23.4.7. Concluding remarks

Present effort to assess the risks related to the introductions of NIS into the Baltic Sea basin via St. Petersburg Harbour area should not be considered as comprehensive and complete. Below we list the most important gaps and steps, which have to be done in the future to improve the current situation.

- comprehensive analysis of international and domestic traffic via St. Petersburg Harbour;
- estimations of future increase in the traffic activity due to construction of new ports in the EGF;
- ballast water studies;
- evaluation of economic and ecological impacts of the established NIS;
- an inventory of NIS in the reservoirs of the rivers Don, Dnieper and Volga with the description of their invasion history;
- an inventory of non-indigenous species which were intensively introduced to the water bodies of the north-west part of Russia with the description of their current distribution trends;
- development of specialised geographic information systems (GIS).

Preliminary studies on these issues have been started at the Zoological Institute of the Russian Academy of Sciences in the framework of the State Programme “Biodiversity” in 1998.

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